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site characteristics of southern california strong-motion earthquake stations

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UNIVERSITY OF CALIFORNIA, LOS ANGELES

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SITE CHARACTERISTICS OF SOUTHERN CALIFORNIA STRONG-MOTION EARTHQUAKE STATIONS

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FOREWORD

The research described in this report, *Site Characteristics of Southern California Strong-Motion Earthquake Stations,* by C. Martin Duke and David J. Leeds, was carried out under the technical direction of the authors and is part of a continuing program in the effects of soil conditions on earthquake damage.

The project was conducted under the sponsorship of the California Department of Public Works, Division of Architecture. The report is submitted in partial fulfillment of State of California Standard Agreement No. 2568.

While it is believed that the underground condition generalizations presented herein are suitable for the purpose for which they were compiled, it is cautioned that they are not suitable for foundation design, nor are they final. Readers of the report who have other relevant information on site conditions at any of the locations described are urged to communicate such information to the authors.

ACKNOWLEDGEMENTS

The project is indebted to many public agencies, city, county, state, and federal, as well as corporations and consulting firms. Numerous city offices throughout the area such as city engineer's offices and water departments supplied requested information. The State Divisions of Architecture and Mines, the Department of Water Resources, the Los Angeles County Flood Control District, and the Water Rights Board provided help as needed. The United States Bureau of Reclamation, Coast and Geodetic Survey, and Navy cooperated. Several foundation engineering companies provided information and consultation: Converse Foundation Engineering Company, LeRoy Crandall & Associates, and Dames & Moore, Inc. Geophysical departments of various oil companies which supplied exploration record fronts from which velocity data could be computed include: Continental Oil Company, Humble Oil Company, Shell Oil Company, Standard Oil Company, and Union Oil Company. The United Geophysical Company provided general information. Other contributors are acknowledged in the text. The quantity of data furnished without cost to the University was encouraging indeed. The authors are grateful to all of the above sources as well as to others not identified here. It is hoped that the compilation and methods suggested will be beneficial to the community.

Messrs. Jefrey R. Ewing and James C. Fraser assisted in the assembly and presentation of the underground data.

TABLE OF CONTENTS

		Page
I.	INTRODUCTION.	1
II.	ELEMENTARY THEORY OF SURFACE AMPLIFICATION OF EARTHQUAKE MOTION	4
III.	SITE CHARACTERISTICS OF SOUTHERN CALIFORNIA STATIONS	18
IV.	STATION LOCATIONS	24
V.	TENTATIVE RECOMMENDATIONS	27
VI.	NEXT STAGE OF RESEARCH.	28
	Appendix A: Station Data	
	Table I - Location of Stations.	30
	Legend Sheet --Station No. 0	
	Station Data Sheets (Nos. 1 to 66)	
	Appendix B: Site Data	
	Appendix C: Amplification Strata	

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I. INTRODUCTION

This report presents the results of an effort to characterize for purposes of seismic analysis the sites of strong-motion earthquake recorder locations in southern California. The data presented permit comparisons among strong motion earthquake records and microtremor records at these sites by means of the site characteristics and elementary amplification theory. The theory is discussed in Chapter II.

The scope of the study embraced all U. S. Coast and Geodetic Survey accelerograph and seismoscope locations, including and southerly from San Luis Obispo, the southern San Joaquin Valley, and Bishop, and embracing Hawthorne, Nevada, Hoover Dam, and San Luis, Arizona, a total of 66 locations. Ultimately, the scope should be expanded to include all sites in the areas from which U.S.C.G.S. earthquake records have been taken.

It is believed that the data presented are sufficiently definitive and reliable to be used in comparisons of earthquake records. Particular attention was given to the top 400 feet, more or less, which is the most critical zone relative to site effects in destructive earthquakes.

Velocity and density profiles from ground surface to basement rock are presented in 66 "Station Data Sheets" in the Appendix. Other information presented includes surface elevation, ground water levels, moisture content, material description, and stratification. A legend sheet Station No. 0 provides a guide for reading the station data sheets.

It is not the purpose of the present report to present recommendations or conclusions, but certain tentative recommendations on station relocations are advanced on the basis of underground information thus far assembled.

1. EFFECT OF SITE

In a recent paper, Duke* has summarized current knowledge, gained from destructive earthquakes, of the effects of soil conditions and local geology on

*Duke, C. Martin, "Effects of Ground on Destructiveness of Large Earthquakes." Journal of the Soil Mechanics and Foundations Division, Proc. A.S.C.E. Paper 1730, August 1958, SM 3.

damage. In general, damage is greater on soft, weak ground, but there are indications that this general trend may be reversed in the case of rigid structures. Observations of damage in certain California earthquakes support these general trends, but it has not been possible to date to correlate satisfactorily with ground conditions the instrumental records obtained with the strong motion seismographs. The latter difficulty is believed to be caused by three factors: inadequate information on ground conditions at the existing instrument sites; insufficient number of instruments; and the fact that the existing instruments have been located with more general considerations in mind.

The concept of taking into account quantitatively, in a seismic structural design, the effects of local ground conditions has been accepted in several countries on the basis of worldwide earthquake experience plus extensive theoretical and experimental research. Notable in this respect is Japan, but also included are Chile, Turkey, Greece, Algeria, and the Soviet Union.

Past progress in earthquake engineering has leaned more strongly on the existing strong-motion program than on any other phase of earthquake research, but the effect of site conditions on damage remains one of the greatest uncertainties. The design of structures with adequate consideration for site conditions, with anticipated benefits through more uniform safety and reduced construction cost, has a good chance of becoming possible as studies in this area are carried ahead.

2. NEED FOR UNDERGROUND DATA

Many strong motion earthquake records have been obtained at sites with differing underground conditions since 1932, when the U. S. Coast and Geodetic Survey network was initiated. To date, however, because of the lack of a systematic assembly of underground data for the stations, next to nothing has been done to determine the extent to which records of earthquake motion reflect the influence of site characteristics. For the same reason, it is not known with confidence whether the network of western United States station locations, composed of approximately 65 accelerographs and 120 seismoscopes, is

optimally designed in terms of gaining the greatest value from records of future earthquakes.

The microtremor method developed by Kanai, and extensively used in Japan, seems to have promise for use in California. Many measurements have been made in the western United States. Validation of the method in California requires intercomparisons of microtremor and strong earthquake records in terms of site conditions.

The underground data presented herein are needed for the above purposes. It should be noted that until a very few years ago it would not have been possible to assemble adequate information for such analyses; many of the data on the station data sheets in the Appendix have become available quite recently.

3. MICROTREMORS

Microtremor observations have been made by the authors at more than 375 sites in the western United States. The observations have included all but a few of the United States strong motion sites, and have been assembled in the project station files.

These records, energized by background "noise" from traffic, industry, etc., have been used extensively in Japan, where the microtremor analysis has been correlated with surface soil characteristics and with earthquake damage. Microtremor periods observed are in the period range of usual buildings from .03 sec. to 2.0 sec.

In Japan the microtremor classification has been written into construction regulations. This dynamic "property" of the site will be considered in the analytical comparison previously mentioned.

The application of microtremor analysis to site performance in earthquakes is supported by a comparison for given sites of dominant microtremor periods with the periods most often found in strong motion accelerograph records. Kanai* obtained good comparisons for a number of small to moderate California earthquakes.

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*Kanai, K., "On the Spectrum of Strong Earthquake Motions." Bull. Earthq. Res. Inst., Tokyo Univ., V.40, March 1962, pp. 71-90.

II. ELEMENTARY THEORY OF SURFACE AMPLIFICATION OF EARTHQUAKE MOTION

1. THE GENERAL SYSTEM

Role of Underground Conditions - Worldwide experience in destructive earthquakes has shown that the kind of ground on which a structure rests has very important effects on the damage it receives in an earthquake. In the last few years, the research efforts of several engineers and seismologists have been directed toward the end of quantifying these effects.

Some perspective may be obtained from the following diagram, which illustrates the earthquake - ground - structure system as a network.

The ground may influence the system in the following ways:

1. As an energy transmitter, it will modulate the frequencies, amplitudes, and durations of the incident earthquake waves.

2. As an energy dissipater, it will transmit part of its own and part of the structure's vibrational energy back into the earth below. It will also absorb energy due to: (1) viscous damping of both incident and reflected waves; and (2) inelastic response to the structure's motion.

3. As a foundation, it may permit both rocking and sideswaying of the structure on its base. Weak ground may permit large differential settlements or horizontal movements of structures during earthquakes, due to readjustment in the ground itself or due to the dynamic forces imposed on it by the structure.

Since about 1930 there have been a number of contributions to the theory of amplification of earthquake wave motion due to surface layers of soil. Most of the contributions are by the Japanese seismologists Sezawa, Kanai, and Takahasi. This section summarizes the theory and presents elementary derivations of several of the relations.

Assumptions - The general system considered is comprised of one or more horizontal layers of soil overlying a horizontal bedrock.

The earthquake waves are assumed to travel vertically in the shallow depths considered. Most of the energy reaching a station can be considered to have traveled in rock from the focus to points on the soil-rock interface below the station. According to Snell's law, waves moving at oblique incidence into the stratified medium considered here are refracted at successively smaller angles to the normal. For typical velocity ratios between rock and soil, a wave incident at the interface at 45^{o} would be refracted at 5^{o} to 10^{o} to the normal. In one observational study (Suzuki 1932)* it was found that the angle of incidence with the vertical of the initial motion of 51 earthquakes averaged 4^{o} at the surface and tended to approach zero as the epicentral distance decreased from 25 kilometers to zero.

The disturbance is assumed to be horizontal and due to S-waves (though the theory is also applicable to P-waves by substitution of the appropriate constants.) S-waves cause vibration normal to the propagation path, with deformation in shear, while P-waves cause longitudinal vibration. Rayleigh and similar surface waves probably are less important than these body waves in the region of strong shaking. In the vicinity of the epicenter, S-waves are considered the most destructive. Strong motion accelerograms obtained in the western United States usually have larger amplitudes in the horizontal than in the vertical components.

The influence of buildings and other structures on the ground motion is neglected. This aspect has recently had attention from Thomson and Kobori, and it is hoped ultimately to be able to handle it in context with surface amplification.

---

*References in Chapter II are to "Bibliography of the Effects of Soil Conditions on Earthquake Damage," by C. Martin Duke, Pub. by Earthq. Engr. Res. Inst., 1958.

Notation - The following symbols will be used.

Particle displacement, velocity, acceleration	u, v, a
Amplitude of u, v, a	U, V, A
Time	t
Vertical distance	x
Wave propagation velocity	c
Period	T
Coefficient of rigidity	μ
Coefficient of equivalent fluid viscosity	μ'
Density	ρ
Impedance ratio	α
Layer thickness	H
Shearing stress	τ
Subscripts	
Number of stratum, from bottom	1, 2, ...
Ground surface	s
Fundamental period	f
Reflected wave	r
Incident wave	i
Transmitted (refracted) wave	t

2. GENERAL RELATIONS

Simple Harmonic Motion - Earthquake motions are assumed to be combinations of simple harmonic motions of varying period and amplitude. Frequently it will be desirable to give special attention to particular ones of these components.

It may easily be shown by successive differentiation that the amplitudes of displacement, velocity, and acceleration of a simple harmonic motion are in the ratio

$$U : V : A = 1 : \frac{2\pi}{T} : \frac{4\pi^2}{T^2} \qquad (1)$$

For two waves with the same period and different displacement amplitudes we may write

$$\frac{U_1}{U_2} = \frac{V_1}{V_2} = \frac{A_1}{A_2} \quad . \tag{2}$$

Free-Surface Amplification. - When a wave of any sort impinges normally on a free surface it is fully reflected. In the process of reflection it is altered one-half cycle in phase. This results in the doubling of amplitude, whence

$$\frac{U_s}{U_i} = 2 \; . \tag{3}$$

Interface Amplification. - A wave moving from a firmer to a softer medium and normally to the interface is partly reflected from the interface and partly transmitted into the adjacent medium. The relative amounts of energy reflected and transmitted are determined by the properties of the two media.

Considering a unit area of the front of an incident wave of constant shear stress, the equality of angular impulse and momentum in a propagation distance $c\,dt$ is expressed by*

$$\tau\, dt = (\rho\, c\, dt)\, v, \quad \text{or}$$

$$\tau = \rho\, c\, v \; .$$

The conditions of continuity of velocity and stress at the interface are

$$v_i - v_r = v_t$$

$$\tau_i + \tau_r = \tau_t$$

where the signs are determined from the consideration that, while the reflected wave is reversed in both propagation direction and particle velocity, the sign of stress is determined by a convention independent of wave or particle direction.

Solving the momentum and continuity equations, and setting $\frac{\rho_t\, c_t}{\rho_i\, c_i} = \alpha$, the impedance ratio, we obtain the particle velocity amplifications

*Timoshenko, S.P. "Theory of Elasticity", McGraw-Hill, 1934, p. 384.

$$\frac{v_r}{v_i} = -\frac{1-\alpha}{1+\alpha} ,$$

$$\frac{v_t}{v_i} = \frac{2}{1+\alpha} .$$

These equations apply for all values of the respective particle velocities and, from Equation (2), we may write

$$\frac{U_r}{U_i} = \frac{V_r}{V_i} = \frac{A_r}{A_i} = -\frac{1-\alpha}{1+\alpha} \qquad (4)$$

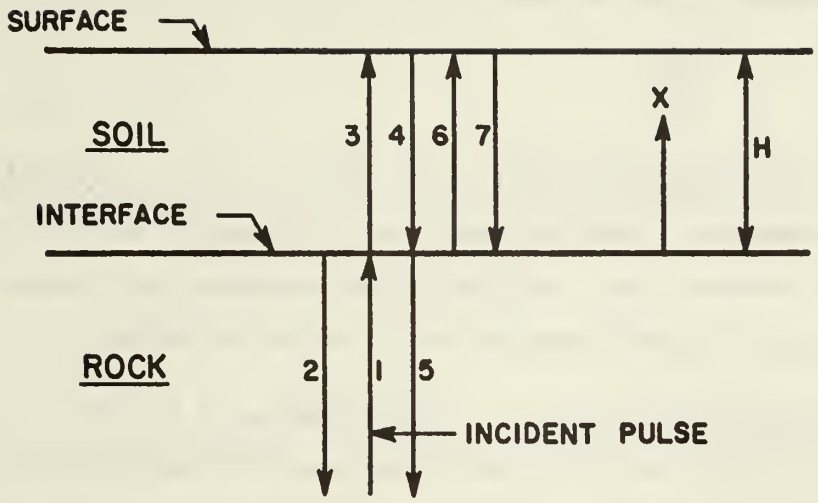
$$\frac{U_t}{U_i} = \frac{V_t}{V_i} = \frac{A_t}{A_i} = \frac{2}{1+\alpha} \qquad (5)$$

3. ONE-LAYER SYSTEM

Figure 1 illustrates a one-layer system. An incident vertical pulse from below will be partly reflected and partly transmitted (refracted) at the interface. The transmitted component will move with a lower velocity and higher amplitude but with approximately the same period and will be totally reflected from the surface.

Part of the energy reflected from the surface will be reflected by the interface back to the surface, and the continuation of this process under a train of waves will result in magnification of surface amplitudes, especially for those wave components which traverse the layer in one-fourth of their period. The process described is influenced by damping due to the solid viscosity of the soil, which, together with "dissipation damping" due to energy transmitted downward through the interface, is the way in which the layer's vibrational energy is absorbed.

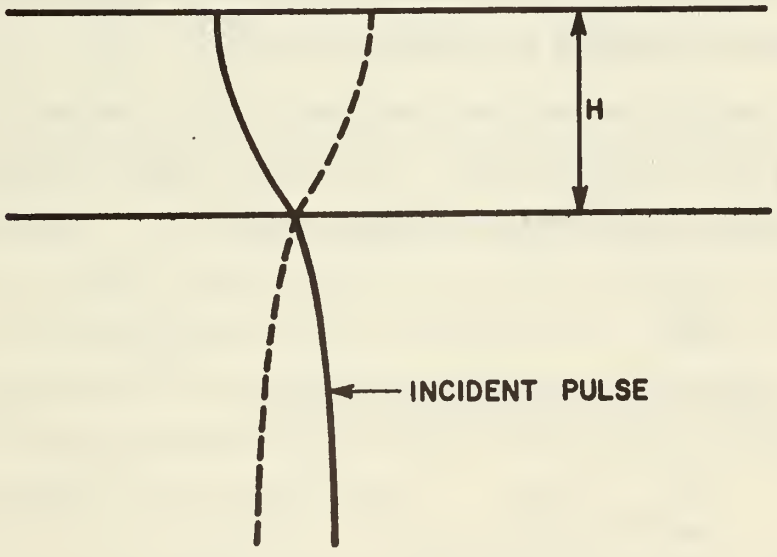
Fundamental Period. - A continuous simple harmonic wave traveling vertically from rock into a homogeneous surface layer will cause maximum surface displacement when one-fourth of its wave length is contained in the layer thickness. The situation is illustrated in Figure 2 which shows a stationary vibration



ONE-LAYER SYSTEM

FIGURE 1

1. Incident wave
2. No. 1 reflected
3. No. 1 transmitted
4. No. 3 reflected
5. No. 4 transmitted
6. No. 4 reflected
7. No. 6 reflected



RESONANCE CONDITION

FIGURE 2

with loop at the surface and node at the interface. This fundamental period of the surface layer is then

$$T_f = \frac{4\,H}{c_2} \quad . \tag{6}$$

Waves with periods which are 1/3, 1/5, 1/7, etc., of Equation (6) will also develop maxima of displacement, but such higher modes are of less importance because their amplitudes are comparatively small and because they are more rapidly damped out by solid viscosity.*

Single Pulse Amplification. - A single pulse of energy, such as a single half wavelength, will be largely dissipated viscoelastically relative to reflections such as Numbers 4, 6, and 7 of Figure 1. In this case the surface amplification may be obtained as the product of Equations (3) and (5),

$$\frac{U_s}{U_i} = \frac{4}{1+\alpha} \quad . \tag{7}$$

Infinite Wave Train Resonant Amplification. - If the assumption is made that solid viscosity is negligible, the above results may be applied to the case of Figure 1 to obtain an expression for surface amplification as influenced by the multiple reflection in a surface layer.

Consider an incident continuous train of simple harmonic waves with period given by Equation (6). Then waves 3 and 4, Figure 1, will cause a total surface displacement of amplification

$$\frac{4}{1+\alpha} \quad .$$

Wave 6 will have a relative amplitude of

$$\frac{2}{1+\alpha} \times \frac{1-\alpha}{1+\alpha} \quad .$$

The displacements of wave 6 are in the same direction as those of wave 2 because, while the reflection 2 - 4 causes a phase change of 180°, wave 2 is

*Kanai, Bull. Earthq, Res. Inst., v. 34, p. 182 (1956).

delayed 180^{o} behind wave 6 due to the time required to traverse distance 2H. Waves 6 and 7 will cause a total surface amplification of

$$\frac{4}{1+\alpha} \times \frac{1-\alpha}{1+\alpha} ,$$

and successive reflections at the surface will cause in-phase surface amplifications of

$$\frac{4}{1+\alpha} \times \left(\frac{1-\alpha}{1+\alpha}\right)^{n-1}$$

where n is the number of the surface reflection. Writing the summation,

$$\frac{U_s}{U_i} = \frac{4}{1+\alpha} \sum_{n=1}^{n=\infty} \left(\frac{1-\alpha}{1+\alpha}\right)^{n-1} = \frac{2}{\alpha} . \tag{8}$$

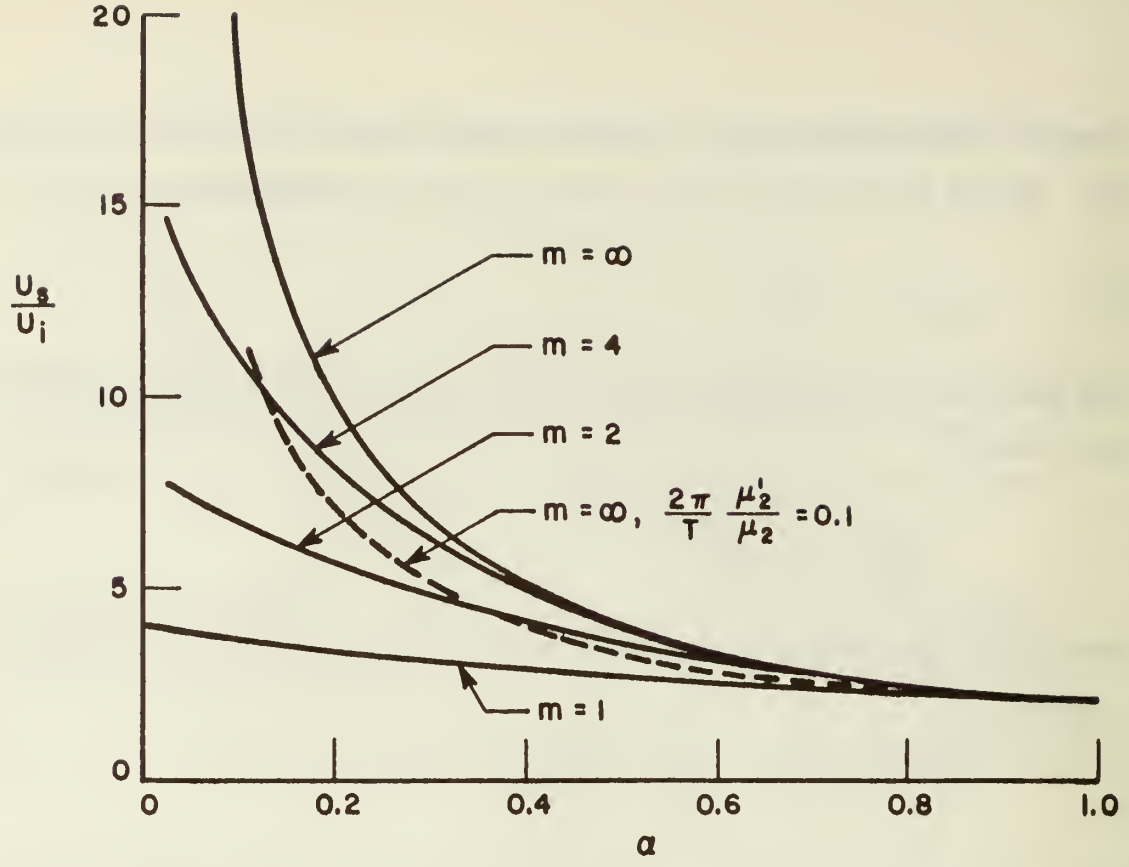
Finite Train Amplification. - Equation (8) applies to the case of resonance, negligible solid viscosity, and an infinitely long wave train. For a finite train of m half wave lengths (m surface reflections), the amplification is expressed by

$$\frac{U_s}{U_i} = \frac{4}{1+\alpha} \sum_{n=1}^{n=m} \left(\frac{1-\alpha}{1+\alpha}\right)^{m-1} = \frac{2}{\alpha} \left(1 - \left(\frac{1-\alpha}{1+\alpha}\right)^{m}\right) \tag{9}$$

whose limit conditions are Equation (8) for $m = \infty$ and Equation (7) for m=1.

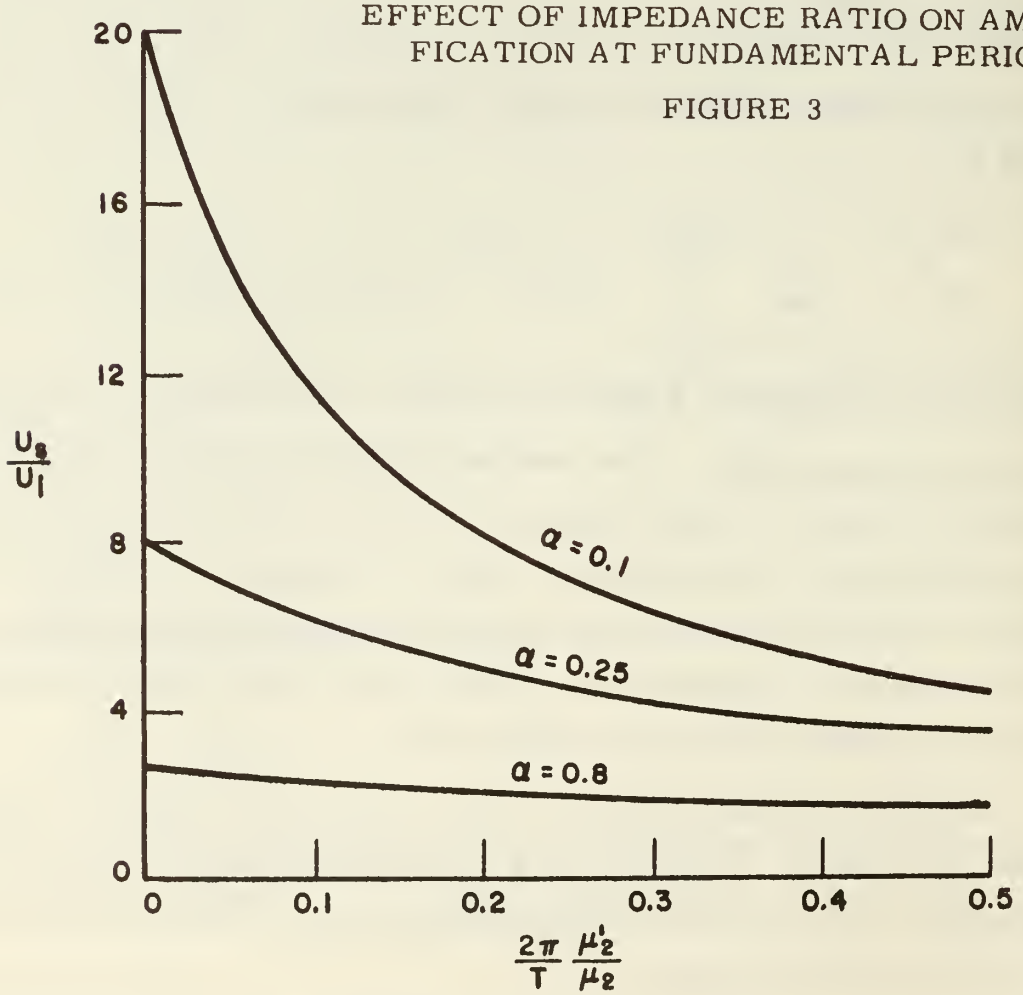
Effect of Impedance Ratio. - The effect of softness of the surface layer is illustrated in Figure 3, where Equations (7), (8), and (9) have been graphed. It is seen that for $\alpha = 1$ all equations reduce to Equation (3). The very large effect of an infinite wave train with respect to a single pulse is shown. For $\alpha = 0.3$ or greater, it appears that a finite train of four half wavelengths has practically the same effect as an infinite train.

The effect of solid viscosity is also illustrated in Figure 3, based on Equation (10), below. Viscosity has a pronounced influence on the surface amplification, but very large amplifications remain in the case of an infinite wave train at resonant period.



EFFECT OF IMPEDANCE RATIO ON AMPLIFICATION AT FUNDAMENTAL PERIOD

FIGURE 3



EFFECT OF SOLID VISCOSITY ON AMPLIFICATION AT FUNDAMENTAL PERIOD (After Kanai 1952)

FIGURE 4

One-Layer Amplification Spectrum. - The equations of motion where solid viscosity is not neglected are

$$\rho_1 \frac{\partial^2 u_1}{\partial t^2} = \mu_1 \frac{\partial^2 u_1}{\partial x^2} + \mu'_1 \frac{\partial}{\partial t} \frac{\partial^2 u_1}{\partial x^2}$$

and

$$\rho_2 \frac{\partial^2 u_2}{\partial t^2} = \mu_2 \frac{\partial^2 u_2}{\partial x^2} + \mu'_2 \frac{\partial}{\partial t} \frac{\partial^2 u_2}{\partial x^2}$$

where x is measured as in Figure 1. Kanai (1950) solved these equations for the case of a continuous sinusoidal incident wave and obtained an amplification spectrum equation,

$$\frac{U_s}{U_i} = \frac{2}{\sqrt{\phi_1^2 + \phi_2^2}} \quad , \tag{10}$$

where ϕ_1 and ϕ_2 are functions of the material properties, incident wave period, and the layer thickness, and the viscosities of bedrock and soil are, respectively, zero and very small.

The maximum amplifications occur at resonance and are shown in Figures 3 and 4. The amplifications for zero viscosity in Figure 4 will be seen to correspond with those for the infinite train in Figure 3.

If viscosity is neglected, Equation (10) becomes (Sezawa 1935)

$$\frac{U_s}{U_i} = \frac{2}{\sqrt{\cos^2\left(\frac{2\pi H}{c_2 T}\right) + \alpha^2 \sin^2\left(\frac{2\pi H}{c_2 T}\right)}} \tag{11}$$

Maximum amplification occurs when $\frac{2\pi H}{c_2 T} = \pi/2,\ 3\pi/2$, etc., corresponding to resonance (Equation 6) and Equation (11) then reduces to Equation (8).

4. MULTI-LAYER SYSTEM

Kanai and Sezawa have carried their theoretical work ahead to include the cases of two and three layers with differing properties. In general,

surface amplification becomes maximum when the bottom interface is a node and is remarkably large when nodes occur at both the bottom interface and an intermediate interface. With increase in number of layers there is a broader range of period of incident wave within which large surface amplification occurs, and thus the amplification spectrum tends to flatten.

Takahasi (1955) developed a simple graphical method of determining the amplification spectrum in a non-viscous multi-layer system based on the theory developed by Sezawa and Kanai. The equation used as a basis for the construction is

$$\frac{U_s}{U_i} = \frac{2}{\sqrt{\cos^2 \phi_m + \alpha_m^2 \sin^2 \phi_m}\ x \ldots . x \sqrt{\cos^2 \phi_2 + \alpha_2^2 \sin^2 \phi_2}} \qquad (12)$$

where the subscript designates the layer number, n, the top layer being called m and bedrock 1. Also,

$$\alpha_n = \frac{\rho_n c_n}{\rho_{n-1} c_{n-1}} ,$$

$$\phi_n = \frac{2\pi H_n}{c_n T} + \theta_n, \quad \tan \theta_n = \alpha_{n+1} \tan \left(\frac{2\pi H_{n+1}}{c_{n+1} T} + \theta_{n+1} \right)$$

For the top layer, $\theta_m = 0$, whence $\phi_m = \frac{2\pi H_m}{c_m T}$ and thus for a single layer Equation (12) reduces to (11).

The construction is repeated, with drawing instruments and a slide rule, for a succession of incident wave periods, and there is obtained the amplification spectrum of the ground. Takahasi points out the analogy between this problem and the propagation of electric waves in a transmission line with one end open, particle velocity and stress corresponding, respectively, to current and voltage.

5. GROUND-MOTION SPECTRUM

The above formulas may be used to obtain graphs of period versus amplification (amplification spectra) for any site where the ground conditions are known quantitatively. A single spectrum represents amplification of displacement, velocity, and acceleration, as shown by Equation (2).

To obtain spectra of ground motion, however, it is necessary to consider additionally the periods and amplitudes of the incident wave motion. One approach is the hypothesis of equipartition of energy, which states that the various harmonic components of an incident earthquake wave contain equal amounts of the total energy of the wave. This hypothesis is supported by some experimental evidence, though it is not applicable for very small periods due to the large viscous damping at these periods. The practical expression of equipartition of energy is the proportionality of period and displacement amplitude of the wave components,

$$U = kT \ ,$$

where k is a constant. Then, from Equation (1),

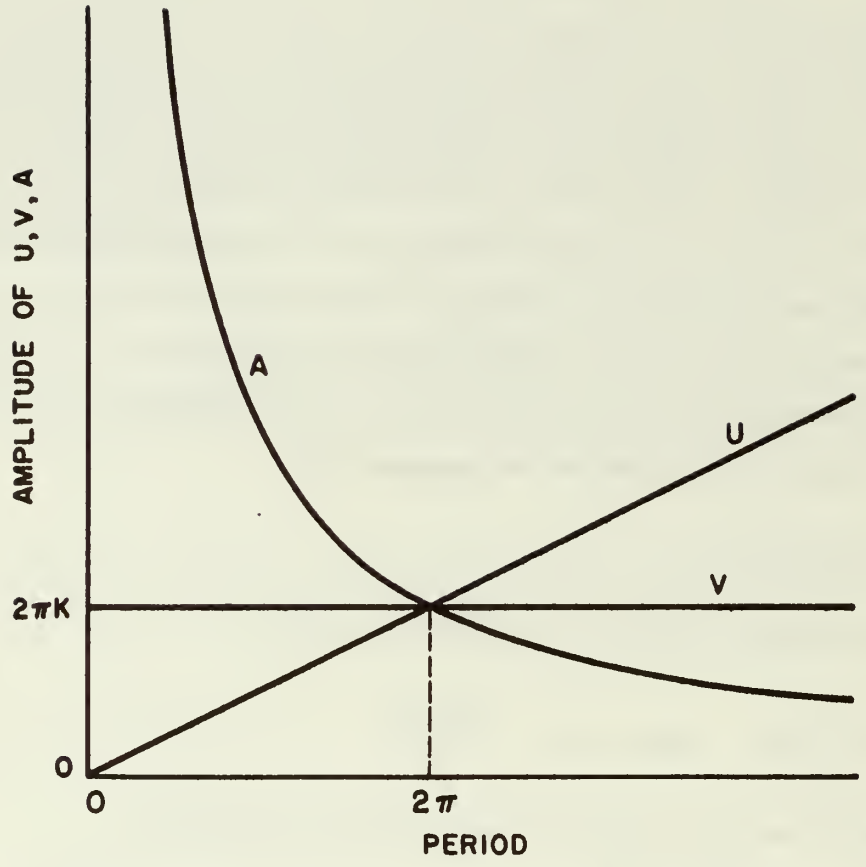
$$V = 2\pi k \qquad \text{and} \qquad A = \frac{4\pi^2 k}{T}$$

The three relationships are shown graphically in Figure 5.

The curves in Figure 5 also represent the shapes of the ground motion spectra for ground conditions where the amplification is independent of the period, i.e., an outcrop of unweathered rock, a deep layer, or a surface layer consisting of a large number of strata.

For a single layer, or for a two- or three-layer system, it is necessary to combine the amplification spectrum with curves like those in Figure 5 to obtain the shapes of the ground motion spectra. In such cases, the ground motion spectra will have peaks at any predominant periods of the amplification spectra.

The above deductions appear to be qualitatively compatible with the characteristics of velocity and acceleration response spectra of strong earthquakes recorded in the western United States.



VARIATION OF AMPLITUDE WITH PERIOD ACCORDING TO EQUIPARTITION OF ENERGY.

FIGURE 5

6. SITE CHARACTERISTICS

It will be observed from the above that the site characteristics for analytical purposes need to be expressed in terms of layer thicknesses, S-wave velocities, material densities, and viscoelastic material properties.

P-wave velocities are much more easily obtained than S-wave velocities, but it is probable that the latter can be estimated from the former in many cases.

Very little information is presently available on equivalent fluid viscosities of earth materials, but it appears from preliminary analyses that useful comparisons can be made neglecting this property.

III. SITE CHARACTERISTICS OF SOUTHERN CALIFORNIA STATIONS

1. STATION DATA SHEETS

The station data sheets shown in the Appendix represent physical conditions at the strong-motion earthquake recorder sites listed in Table I. The station data sheets show the underground features affecting the character of the earthquake wave on the surface. A legend sheet (in color) precedes the station data sheets and explains the symbols used.

The selection of data presented on the sheets was accomplished from concurrent study of all available underground information pertaining to the respective sites.* Many compromises were dictated by availability of data. In many cases, nearby data and interpolation were used in the absence of detailed data for the precise location. Nonetheless, the results are considered sufficiently definitive and reliable for the analyses planned.

All available information resources were utilized within the limitations of (1) the expense of field or laboratory measurement, and (2) the proprietary nature of some information. Published papers, open file reports, and publicly-owned data were quoted freely, but unpublished material was used without citation.

The properties presented on the sheets are: P-wave velocities, stratification and material description, water content, densities, and earthquake-dated ground water levels. Surface elevation, and position of the recorder, if not at grade, are shown also for each site. These properties are shown in more detail near the surface; their effects diminish as the depth increases beyond perhaps 400 ft.

Near-surface soil mechanics data, (usually to about 30 or 40 feet, but occasionally to 100 feet near major structures) were available from foundation

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*California State Division of Mines, California Journal of Mines and Geology, Bulletins, Special Reports.
Sakurai, Fred H., "Soil Conditions on Campus" Senior Project (SPC-21), Dept. of Engineering, University of California, Los Angeles, Unpublished, 1958.
See "Acknowledgements" and subsequent references.

and structural engineers or from building owners. These data were utilized exhaustively in preparing the station data sheets to the depths indicated. Densities, material descriptions, water content, and a variety of soil mechanics properties are usually measured in foundation investigations. These reports, when available, are considered a primary source of information at the shallower depths.

2. VELOCITY

The P-wave velocity values shown are from several sources. The near-surface measurements (to a depth of about 50 feet) were made by the project staff with a single-channel velocity timer, using a sledge hammer source. Observations were made in the Colton-Riverside area in cooperation with Department of Water Resources personnel. Other near-surface velocities were determined with a similar apparatus loaned to the project through the courtesy of Dames & Moore, Inc. These are the only values that were actually measured by project personnel.

Values for depths to about 500 feet were obtained by treating the first arrivals on seismic-exploration reflection records as refraction spreads. Slant ranges were used to construct a travel-time chart. These record "fronts" were obtained for a large number of sites near instrument locations through the courtesy of several oil companies. They also furnished other uphole and interval velocity data to enable the construction of velocity profiles from surface to basement. Difficulty was encountered in the utilization of the record fronts, as reflection shots are generally fired below the "weathered" layers and below the water table. Theory exists for surface-fired shots in refraction exploration; but an analytical method had to be worked out for the hybrid utilization of the reflection data. The results obtained by this method are thought to be valid.

Estimates were made using similar material at equivalent depths for sites outside the heavily prospected areas. Data have been published for a few localities where special studies were conducted such as the U. S. Geological

Survey work in Owens Valley,* Robert Kovach et al, in the Imperial Valley† and Stuart Smith and Hewett Dix at the California Institute of Technology. Gordon Eaton of the University of California, Riverside provided unpublished refraction data for that area.‡ The City of Pasadena Water Department supplied the results of their refraction work near Monk Hill.

All sources were combined freely in order to construct the best possible estimate of a velocity profile for each site. As additional data become available, the estimates for specific sites will be refined or corrected.

3. DENSITY

Density estimates at depth are based principally on the published work of Schoellhamer and Woodford, 1951, Thane H. McCulloh, 1957 and 1960, R. Wuerker, 1956, and Ekis, 1934.§ Densities for the first 30 to 100 feet were taken from previously mentioned soil mechanics engineering reports for building foundations. Where exact values were unobtainable, estimates are based on measurements of similar materials (lithology and age) at comparable

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*Pakiser, L.C., M. F. Kane, "Geophysical Study of Cenozoic Structures of Northern Owens Valley, California", Geophysics, Vol. 27, No. 3, pp. 334-342, June 1962.

†Kovach, Robert L., Clarence R. Allen, Frank Press. "Geophysical Investigation in the Colorado Delta Region". Journal of Geophysical Research, Vol. 67, No. 7, pp. 2845-2871. July, 1962.

‡Personal Communication.

§Schoellhamer, J.E., A. O. Woodford, "The Floor of the Los Angeles Basin, Los Angeles, Orange, and San Bernardino Counties, California". U. S. Geological Survey, Oil and Gas Investigations, Map OM 117, 1951.
McCulloh, Thane H., "Simple Bouger Gravity and Generalized Geologic Map of the Northwestern Part of the Los Angeles Basin, California". U. S. Geological Survey, Geophysical Investigation, Map GP 149, 1957.
McCulloh, Thane H., "Gravity Variations and the Geology of the Los Angeles Basin of California", Geological Survey Research in 1960. U. S. Geological Survey, Professional Paper 400-B, No. 150, pp. B320-B325, 1960.
Wuerker, Rudolph G., "Annotated Tables of Strength and Elastic Properties of Rocks", Petroleum Branch American Institute Mining Engineers, 1956.
Ekis, R., "Geology and Ground-Water Storage Capacity of Valley Fill", South Coastal Basin Investigation, California Div. Water Resources Bulletin No. 45, 279, pp., 1934.

depths. Densities of surface materials have also been taken from Corbató, 1960.* The principal contributor to the study of densities, and their geologic depth and areal distribution is Thane H. McCulloh, University of California, Riverside. As indicated in his 1960 paper, the work is continuing and a comprehensive report should be forthcoming.

4. GROUND WATER LEVELS

An effort was made in the study to present ground-water levels for the dates of recorded destructive earthquakes. The 1933, 1941, and 1952 earthquakes are of particular interest, as well as a current reading or estimate. In many instances it is not possible to find the level on a given date; there are too few ground-water levels known. Additional estimates are possible from water-supply people familiar with the areas. These data will have to be extended as needed during the utilization of the station data sheets.

The influence of water table on surface amplification is in need of further research. Contradictory opinions exist.†

5. LOGS

The lithology, or material description, below that derived from the investigation of building foundations, is taken from water-well logs. These logs generally lack sample or cutting descriptions of the professional engineer or geologist but are often quite detailed and useful. In addition, water levels are usually available with the well logs. Some water wells penetrate as deep as 1000 feet, and a few go down to 5000 or 6000 feet and into basement rock. Reports by the State Department of Water Resources, U. S. Geological

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*Corbató, Charles Edward, "Gravity Investigation of the San Fernando Valley, California", Ph.D. Dissertation, University of California, Los Angeles, 1960.

†Iida, K., "On the Elastic Properties of Soil, Particularly in Relation to its Water Content". Bulletin Earthquake Research Institute, Vol. 18, Part 4, December 1940, pp. 675-691.
Kanai, K., Personal Communication.

Survey, and the State Water Rights Board, cover some of the areas in adequate detail.*

Deep lithology, occasionally with detailed description, is available in oil-well logs. Basement rock penetration, if achieved, is always obvious. Logs from wells in oil fields are not individually as important as "wildcat" logs, since the producing fields are usually on anomalous structural highs, with nontypical faulting and formation development. The stratigraphy and lithology of the producing fields are so well known that the data necessarily provide the framework for interpolation to sites between the fields. Much has been published by the California State Division of Oil and Gas† on oil fields, and by the Division of Mines on nonproducing areas. Electric logs of both water and oil wells also provide certain valuable information.

The reliability of these data varies. Fortunately, data from the near-surface zone, believed to be most significant, have the highest degree of reliability. The deeper water-well data have less accurate descriptions and fewer physical determinations. The quantity of deep data is usually so great

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*Thomas, Robert G., John J. Landry, Robert J. Turney, "Planned Utilization of the Ground Water Basins of the Coastal Plain of Los Angeles County. Appendix A. Ground Water Geology." California State Department of Water Resources, Bulletin 104, 1961.

Conkling, Harold, George B. Gleason, E. C. Marliave, Raymond Basin Area Reference, Report of Referee, City of Pasadena vs City of Alhambra, Div. of Water Resources, 1953.

U. S. Geological Survey, Water Supply Papers, Professional Papers, Open-File Reports.

Woodring, W. P., M. N. Bramlette and W. S. W. Kew, "Geology and Paleontology of Palos Verdes Hills, California." U. S. Geological Survey, Professional Paper 207, 1946.

Finlayson, Donald J., "San Fernando Valley Reference", Draft of Report of Referee, City of Los Angeles vs City of San Fernando, Water Rights Board, 1961.

†California State Division of Oil and Gas, "California Oil and Gas Fields, Maps and Data Sheets", Two volumes, California Division Oil & Gas, Department Natural Resources, 1960, 1961.

Oil & Gas Supervisor, State of California, "Summary of Operations, California Oil Fields", California Division Oil & Gas, Department Natural Resources, 1919 - 1961.

that, although reliable, it must be generalized grossly.

A composite of conventional soil mechanics classification symbols (Unified Soil Classification System) and geologic symbols is used to describe the lithology. In many cases the language of the driller has been preserved where conversion to a standard term was not apparent, but an appropriate symbol is used.

In most instances geologic formation names are given, as a helpful descriptive term and to indicate relative age and implied degree of compaction. Many problems arise in a lack of unanimity of opinion of the investigators quoted, or a paucity of information about some of the areas.*

6. WATER CONTENT

Water content of the soils is given only where it has been fairly well measured; however, discussions with people working with cores and samples from all depths indicate that sediments and basement rocks in the Los Angeles Basin are fully saturated from the water table downward. This is reflected in the density profiles shown on the station data sheets. The figures given are quite reliable as they are generally measurements in soil mechanics laboratories by competent personnel, though values usually fluctuate considerably with depth.

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*Hoots, H. W., "Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California". U. S. Geological Survey, Professional Paper 165-C. 1931.

Laiming, Boris, Editor, "AAPG - SEPM - SES Guidebook". Joint Annual Meeting, Los Angeles, 1952.

Jahns, Richard H., Editor, "Geology of Southern California", California State Division of Mines, Bulletin 170, 1954.

Higgins, James W., Editor, "A Guide to the Geology and Oil Fields of Los Angeles and Ventura Regions", Pac. Section, Amer. Assn. Petrol. Geol., Annual Meeting AAPG - SEPM Los Angeles, 1958.

Lamar, Donald Lee, "Structural Evolution of the Northern Margin of the Los Angeles Basin". Ph.D. dissertation. University of California, Los Angeles 1961.

IV. STATION LOCATIONS

There are two principal kinds of strong-motion earthquake recording instruments installed at the 66 sites tabulated in the Appendix. There is a basic network of three-component, time-based recording accelerographs at 20 sites and approximately 50 inexpensive "seismoscopes" which overlap some of the accelerograph stations. Several sites studied had temporary instruments during high regional seismic activity, and some of the sites have a second or third instrument on upper floors or nearby. A small number of other instruments are also in use: 10-second, long period displacement meters, 2.5 second Carder displacement meters, and Weed Seismographs.

The Southern California group presently under study is part of a larger array of approximately 85 accelerographs and 120 seismoscopes operated by the U.S. Coast and Geodetic Survey and stretching from Seattle, Washington to Santiago, Chile. Eight strong motion instruments were installed between July 1932 and the 1933 Long Beach Earthquake, and 48 were in operation by November 1934. It is interesting to note that at the time, Beno Gutenberg wrote on the effect of the station*:

> "There is a distinct difference between the short periods prevailing at distance less than 50 kilometers at different stations. This should be attributed, therefore, to free vibrations of thinner layers which differ from station to station."

This study for the first time details the thicknesses and physical properties of the "thinner layers"; the periods obtained in microtremor studies will be utilized as the project continues.

The basis for the location of seismoscope stations was set forth in a report of the Earthquake Engineering Research Institute, Seismometer Location

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*"Earthquake Investigations in California 1934-1935", U. S. Coast & Geodetic Survey Special Publication No. 201, p. 214, 1936.

Committee, dated February 4, 1961, by C. M. Duke. The general criteria of the location scheme were:

1. Surface soil type, alluvium depth, and depth to basement rock;
2. Seismicity;
3. Ties with existing instruments and previous studies;
4. Availability of suitable instrument housings;
5. Quality and quantity of information as to soils and geology;
6. Probable interests of various agencies in cooperating with and/or supporting the program.

Most of the same criteria guided the original accelerograph site selection except, of course, the ties to previous studies and the emphasis on site conditions. An effort was made originally to spot the accelerographs about 100 miles apart, in cities (which are generally located on alluvial areas). California's cities are conveniently situated to satisfy this criterion. As the program expanded, other forces dictated the locations, giving rise to the concentration of instruments in the urban areas where correlative seismic effects on structures might be expected.

In the location of seismoscopes, additional factors were considered. It was not felt desirable to locate an instrument singly, without nearby accelerographs with proven performance characteristics to be used as reference. It was also desired to obtain ground motion data at several nearby points on varying types of ground. Therefore, the seismoscopes were located in clusters around accelerographs, with seismoscopes actually mounted on the same foundation pads as accelerographs in several cases. When the seismoscopes have attained a reliable experience record, they may perhaps be used singly or without the accelerograph reference. The conservative practice at present permits comparison between accelerographs and seismoscopes at a base station and between nearby seismoscopes with varying soil and geologic settings.

The reasons for specific concentrations of instruments are usually clear from inspection of a geologic map. The several in the San Bernardino - Riverside

area are on a line from the mountains through deep aluvium and back on to hard rock, with Colton as an accelerograph reference. The large group in the Pasadena embayment reoccupy the sites used by Gutenberg in 1957 in a comparative study using two identical instruments with small earthquakes.* The profiles across the Los Angeles Basin have instruments on enormously deep sediments, and on structural highs and basement outcrops. Terrace topography is investigated in the West Los Angeles area. The four El Centro instruments are, as far as can be determined, on identical sites, which should prove an interesting test of the thesis of this project. Table I lists the locations of the 66 sites for which station data sheets are presented.

An additional group of 22 seismoscope stations have been established by the City of Los Angeles Department of Water and Power. They are at eleven earth-fill dams on crests and abutments. The records will supplement those from the 66 sites in this report.

*Gutenberg, Beno, "Effects of Ground on Earthquake Motion". Bulletin Seismological Society of America, Vol. 47, No. 3, pp. 221-250, July, 1957.

V. TENTATIVE RECOMMENDATIONS

A few tentative recommendations for the relocation of stations can be made at this time.

The heavy concentration of seismoscopes in the Pasadena area can be reduced, after one good set of records is obtained. The same instruments may be then relocated at others of the 1957 Gutenberg* sites.

The Edison Building accelerograph may not be essential because of the two in the Subway Terminal Building. The Edison Building instrument could be relocated.

The top floor instruments in the Subway Terminal Building and Occidental Life Building perform closely parallel functions. One could be reinstalled at a Wilshire Boulevard address in a more modern building.

There is a need for instruments at Indio and on the east side of the San Joaquin Valley.

The Colton accelerograph site is in a particularly disadvantageous location. While near a source of possible earthquakes it is on a small fault block that could isolate it from the maximum motion. It should be moved to a site several miles east of San Bernardino.

It is not the purpose of this report to draw conclusions or to make firm recommendations.

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*op. cit.

VI. NEXT PHASE OF RESEARCH

Planning for the next phase of research has emphasis on the following items:

(1) The computation of amplification spectra for about one third each of the existing California accelerograph and seismoscope sites.

(2) The recommendation of desirable changes in instrument locations to give better data on the effects of site characteristics in future earthquakes.

(3) The application of amplification spectra to all available strong motion earthquake and microtremor records at the above sites to illuminate the nature and extent of the influence of site characteristics on earthquake motions.

(4) The preparation of tentative recommendations for earthquake resistive design to account for site conditions in Southern California.

(5) The compilation of all available data on site parameters pertinent to earthquake motion at strong motion recorder sites in Northern California.

In the longer range picture, it will be necessary to incorporate into the analysis the interaction of the ground and the superstructure.

The ultimate problem is to evolve a method for rating individual building sites as to probable maximum earthquake motion to be experienced in the design life of the building.

APPENDIX A

Station Data

TABLE I

Locations of Stations

Los Angeles Area

1. Subway Terminal Building. Broadway between 4th and 5th Streets. Subbasement passenger loading ramp, 60 feet under Hill Street. Accelerograph, displacement meter, seismoscope, and 13th floor accelerograph.
2. Edison Building. 5th Street and Grand Avenue. Accelerograph and seismoscope.
3. Occidental Life Building (formerly Chamber of Commerce Building). Broadway at 12th Street. Basement accelerograph and seismoscope, and 13th floor accelerograph.
4. Exposition Park. Museum of Science and Industry. 39th Street. Seismoscope.
5. Vernon, Central Manufacturing District Building, 4814 Loma Vista Avenue. Accelerograph and seismoscope.
6. Huntington Park City Hall. Miles and Zoe Streets. Seismoscope.
7. Hollywood Storage Building (Bekins), Highland Avenue at Santa Monica Blvd. Basement, penthouse and remote accelerographs, remote seismoscope in Pacific Electric Lot.
8. Hancock Park (LaBrea Tar Pits) 5801 Wilshire. Seismoscope.
9. Westwood, Engineering Building, Unit 1B, University of California. Formerly Physics Building Basement. Accelerograph, building strain recorder, and seismoscope.
10. West Los Angeles Public Library. Santa Monica Blvd. at Purdue Avenue. Seismoscope.
11. Brentwood, 1110 Bundy Drive. Residence of C. M. Duke, Seismoscope.
12. Pacific Palisades, 15218 Friends Street. Residence of G. Tauxe. Seismoscope.
13. Windsor Hills Elementary School (Baldwin Hills) 1552 Overdale Drive. Seismoscope.
14. Playa Del Rey Elementary School. Ballona Creek, 12221 Juniette St., near Jefferson & Centinela. Seismoscope.
15. Westchester, 7643 Truxton Avenue. Residence of D. J. Leeds. Seismoscope.
16. Hyperion Sewage Treatment Plant. 11300 Vista Del Mar Blvd. Seismoscope.

17. Harbor City, Narbonne High School. 23100 South Western Avenue. Seismoscope.

18. San Pedro High School, 1001 West 15th Street. Seismoscope.

19. Long Beach, Terminal Island. Southern California Edison Co. Power Plant. Accelerograph and seismoscope.

20. Long Beach, Municipal Utilities Building. Broadway at Pacific Avenue. Accelerograph and seismoscope.

21. Compton City Schools Administration Building, 604 Tamarind Avenue. Seismoscope.

22. South Gate High School. Firestone Blvd. at Elizabeth Ave. Seismoscope.

23. Highland Park, 3950 Scandia Way, Residence of E. Frackelton. Seismoscope.

24. Elysian Heights Elementary School. Echo Park Avenue at Baxter Street. Seismocope.

25. Glendale. Herbert Hoover High School, 613 Glenwood Road, Seismoscope.

26. Van Nuys High School, 6400 North Hamlin Street. Seismoscope.

Pasadena Area

27. Mt. Wilson. Instrument Shed. California Institute of Technology Seismograph Station. Teleseismic instruments and seismoscope.

28. Altadena. 1972 Skyview Drive. Residence of F. Press. Seismoscope.

29. Altadena. 416 Devirian Place, Residence of R. Gilman. Seismoscope.

30. Washington Junior High School. Fair Oaks Avenue at Grandview St. Seismoscope.

31. John Muir High School. Lincoln Avenue at LaCanada Avenue. Seismoscope.

32. 1545 Ontario Avenue. Residence of N. Motta. Seismoscope.

33. Hale Elementary School. 2550 Paloma Street. Seismoscope.

34. 1695 Corson Street. Residence of J. M. Nordquist. Seismoscope.

35. Pasadena Star News Building. East Colorado Blvd. at Oakland Avenue. Seismoscope.

36. Seismological Laboratory, California Institute of Technology, 220 North San Rafael Avenue. Teleseismic instruments and seismoscope.

37. San Rafael Elementary School, Eagle Rock, 1090 Nithsdale Road Seismoscope.

38. Garfield Elementary School, 540 South Pasadena Avenue at California Blvd. Seismoscope.

39. California Institute of Technology, Athenaeum, California Street at Hill Street. Accelerograph, Weed seismograph, seismoscope.

40. San Marino City Hall. Huntington Drive at San Marino Ave. Seismoscope.

41. Alhambra, 1033 Almansor Street, Residence of V. Taylor. Seismoscope.

42. East Los Angeles Junior College, 5357 East Brooklyn Drive. Audiotorium Boiler Room. Seismoscope.

43. Santa Ana Court House, 8th Street and Broadway. Accelerograph and seismoscope.

East

44. Bishop. Los Angeles Department of Water & Power Service Garage. Accelerograph.

45. Hawthorne, Nevada. U. S. Naval Ammunition Depot. Administration Building. Accelerograph.

46. Hoover Dam, 1215 Gallery, Nevada. Accelerograph.

47. Hoover Dam, Nevada Intake Tower. Accelerograph.

48. Hoover Dam, Oil House, Nevada. Accelerograph.

San Bernardino - Riverside Counties

49. Table Mt. Formerly Smithsonian Solar Observatory. Now U. S. Forest Service, near Wrightwood. Tiltmeter and seismoscope.

50. Arrowhead Springs. U. S. Forest Service Building. Seismoscope.

51. San Bernardino Post Office, 5th & "D" Streets. Weed seismograph and seismoscope.

52. Colton, Southern California Edison Company Distribution Station. Accelerograph, displacement meter, and seismoscope.

53. Riverside, California Institute of Technology Seismograph Station. Locust & Houghton Streets. Teleseismic instruments and seismoscope.

54. Riverside, Lincoln Elementary School, 3300 Lime Street. Seismoscope.

Kern County

55. Taft, Lincoln Junior High School, 6th Street at Woodrow. Accelerograph.

56. Bakersfield High School, Harvey Audiotorium, 14th and H Streets. Accelerograph.

57. Arvin High School. One mile north of city. Former location of accelerograph.

Central Coast

58. Port Hueneme. U. S. Naval Civil Engineering Laboratory, U.S.N. Construction Battalion Center. Accelerograph.

59. Santa Barbara County Court House. Anapamu and Santa Barbara Streets. Accelerograph.

60. Cachuma Dam Crest. Accelerograph.

61. Cachuma Dam Gate House. Accelerograph.

62. San Luis Obispo Municipal Recreation Building. Santa Rosa and Mill Streets. Accelerograph.

Imperial Valley & South

63. San Diego, San Diego Gas & Electric Company Utilities Bldg. 10th and Imperial Streets. Accelerograph.

64. El Centro - 4 sites

    Imperial Valley Irrigation District Substation.
    Accelerograph and seismoscope

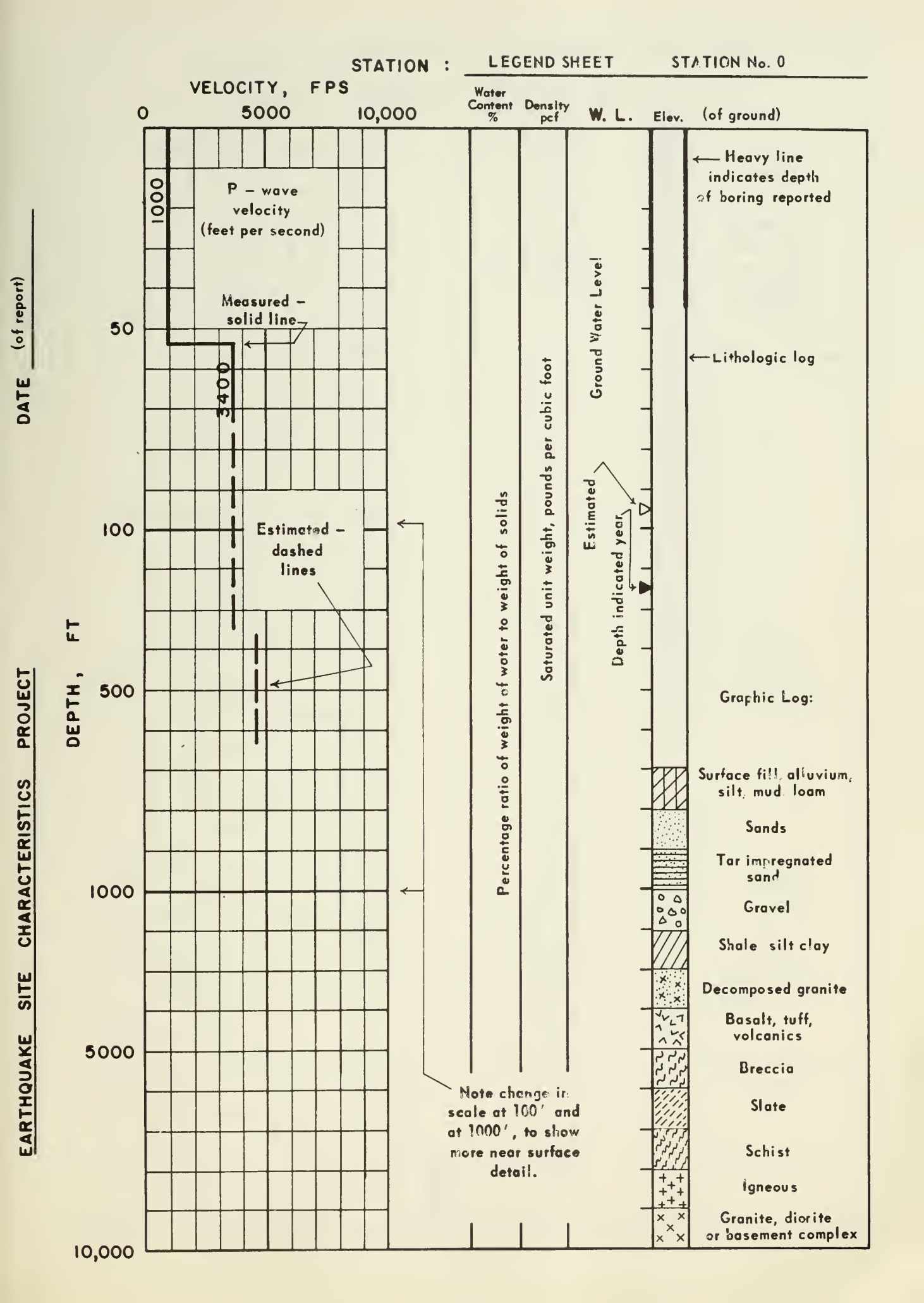
    El Centro Water Works
    Seismoscope

    El Centro High School, Main & North 9th Streets.
    Seismoscope

    Imperial Irrigation District Steam Plant
    Displacement meter and seismoscope

65. Imperial Dam. Pumphouse. Seismoscope.

66. San Luis, Arizona. U. S. Customs House. Seismoscope.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10,000
Water Content %
Density pcf
W. L.
Elev.
(of ground)
DATE (of report)
EARTHQUAKE SITE CHARACTERISTICS PROJECT
DEPTH, FT
50
100
500
1000
5000
10,000
1000
3400
P – wave velocity (feet per second)
Measured – solid line
Estimated – dashed lines
Percentage ratio of weight of water to weight of solids
Saturated unit weight, pounds per cubic foot
Ground Water Level
Estimated
Depth indicated year
Note change in scale at 100' and at 1000', to show more near surface detail.
← Heavy line indicates depth of boring reported
← Lithologic log
Graphic Log:
Surface fill, alluvium, silt, mud loam
Sands
Tar impregnated sand
Gravel
Shale silt clay
Decomposed granite
Basalt, tuff, volcanics
Breccia
Slate
Schist
Igneous
Granite, diorite or basement complex

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DATE 11/1/62

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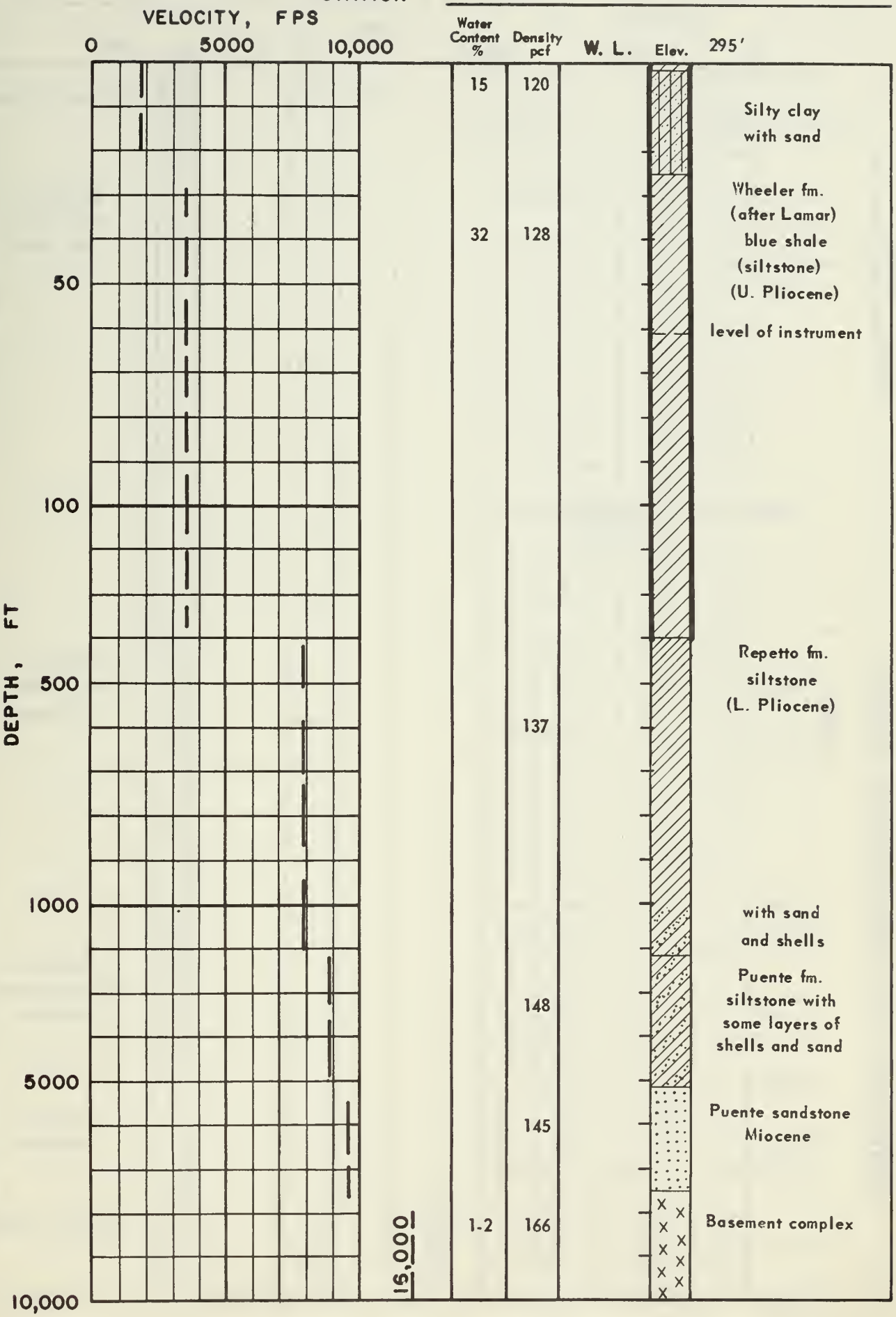

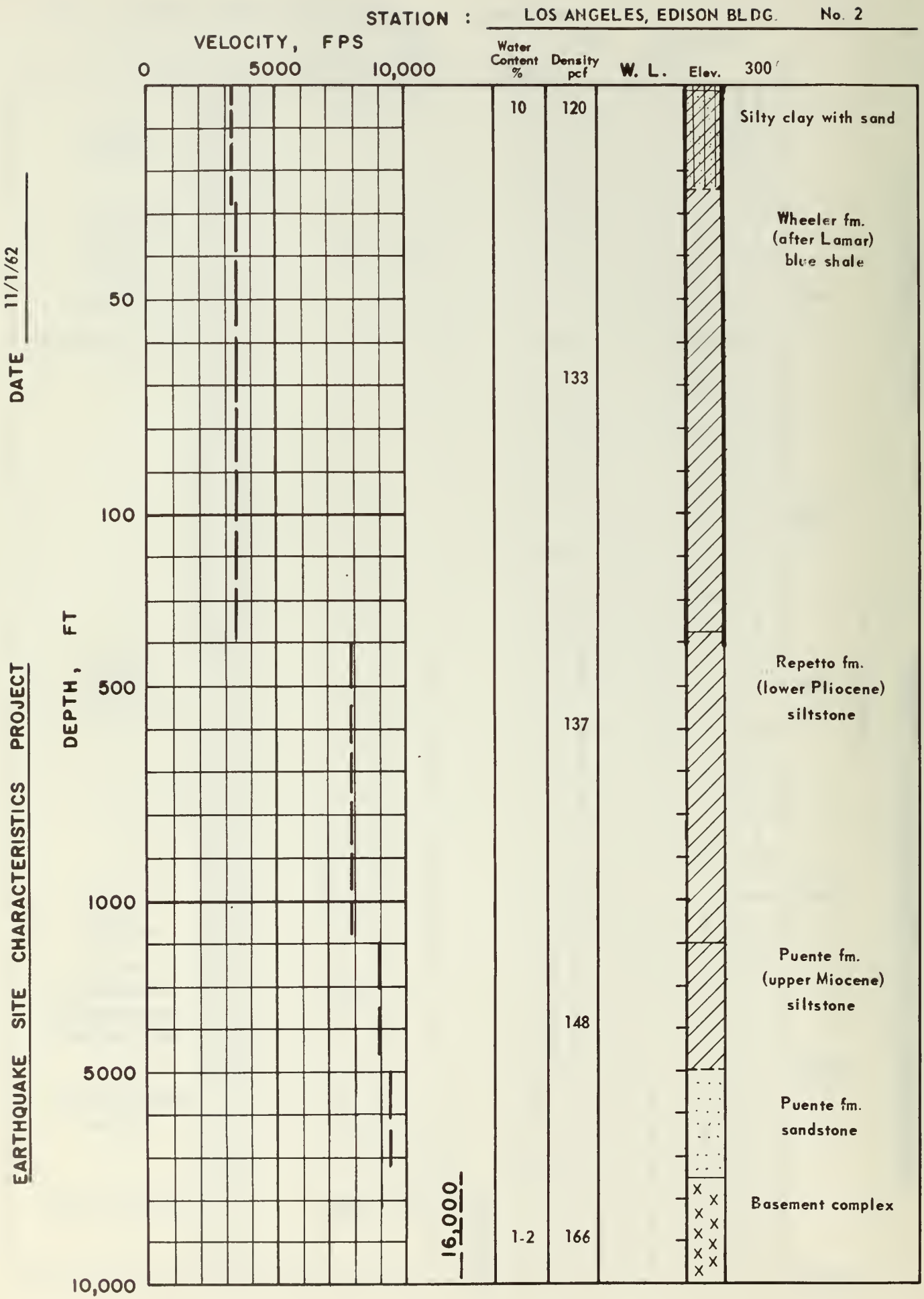
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0
5000
10,000
Water Content %
Density pcf
W. L.
Elev.
300'
10
120
133
137
148
1-2
166
16,000
Silty clay with sand
Wheeler fm. (after Lamar) blue shale
Repetto fm. (lower Pliocene) siltstone
Puente fm. (upper Miocene) siltstone
Puente fm. sandstone
Basement complex
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100
500
1000
5000
10,000
DATE 11/1/62
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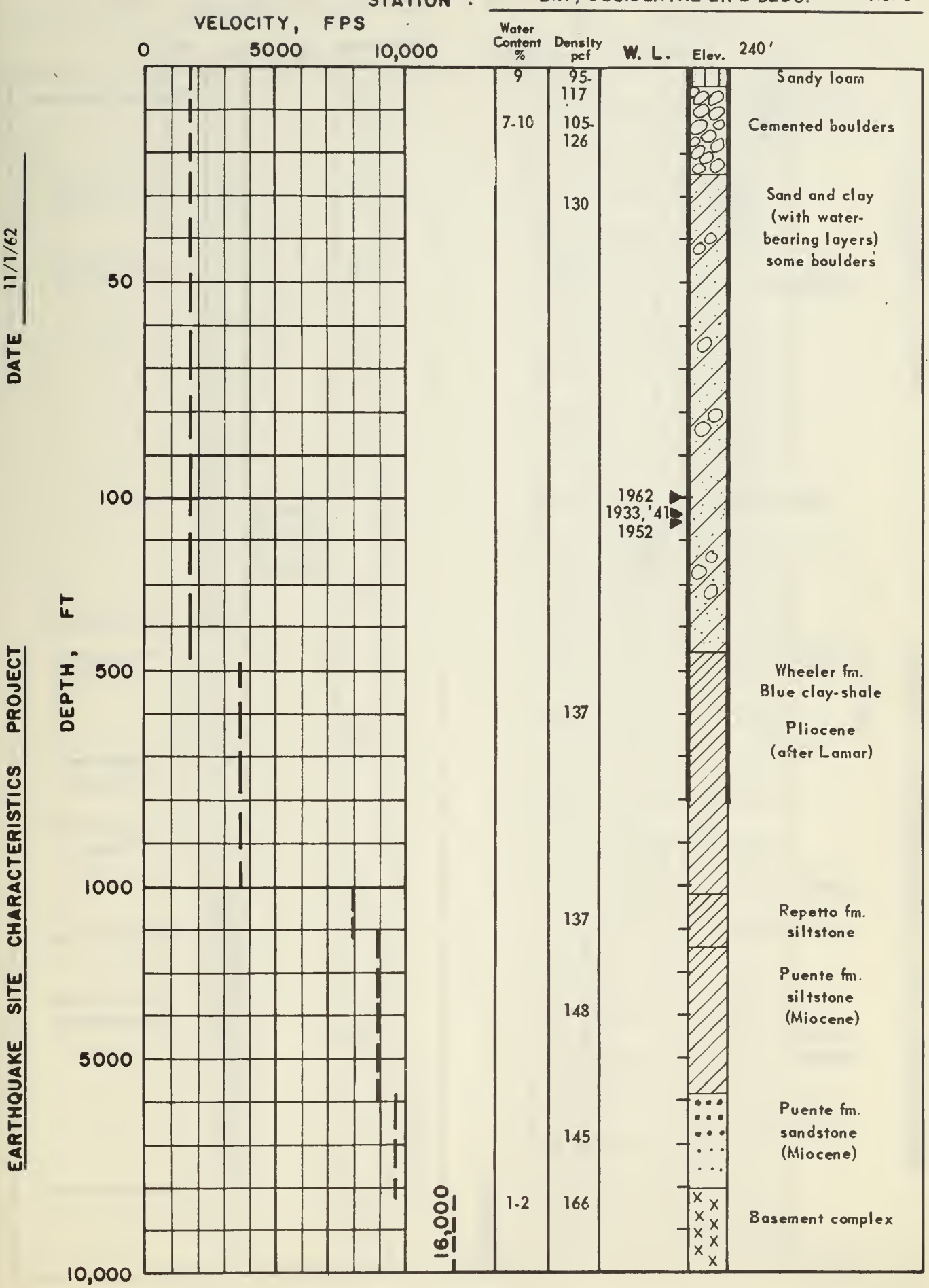
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5000
10,000
Water Content %
Density pcf
W. L.
Elev. 240'
9
95-117
7-10
105-126
130
137
137
148
145
1-2
166
1962
1933,'41
1952
16,000
Sandy loam
Cemented boulders
Sand and clay (with water-bearing layers) some boulders
Wheeler fm. Blue clay-shale
Pliocene (after Lamar)
Repetto fm. siltstone
Puente fm. siltstone (Miocene)
Puente fm. sandstone (Miocene)
Basement complex
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1000
5000
10,000
DATE 11/1/62
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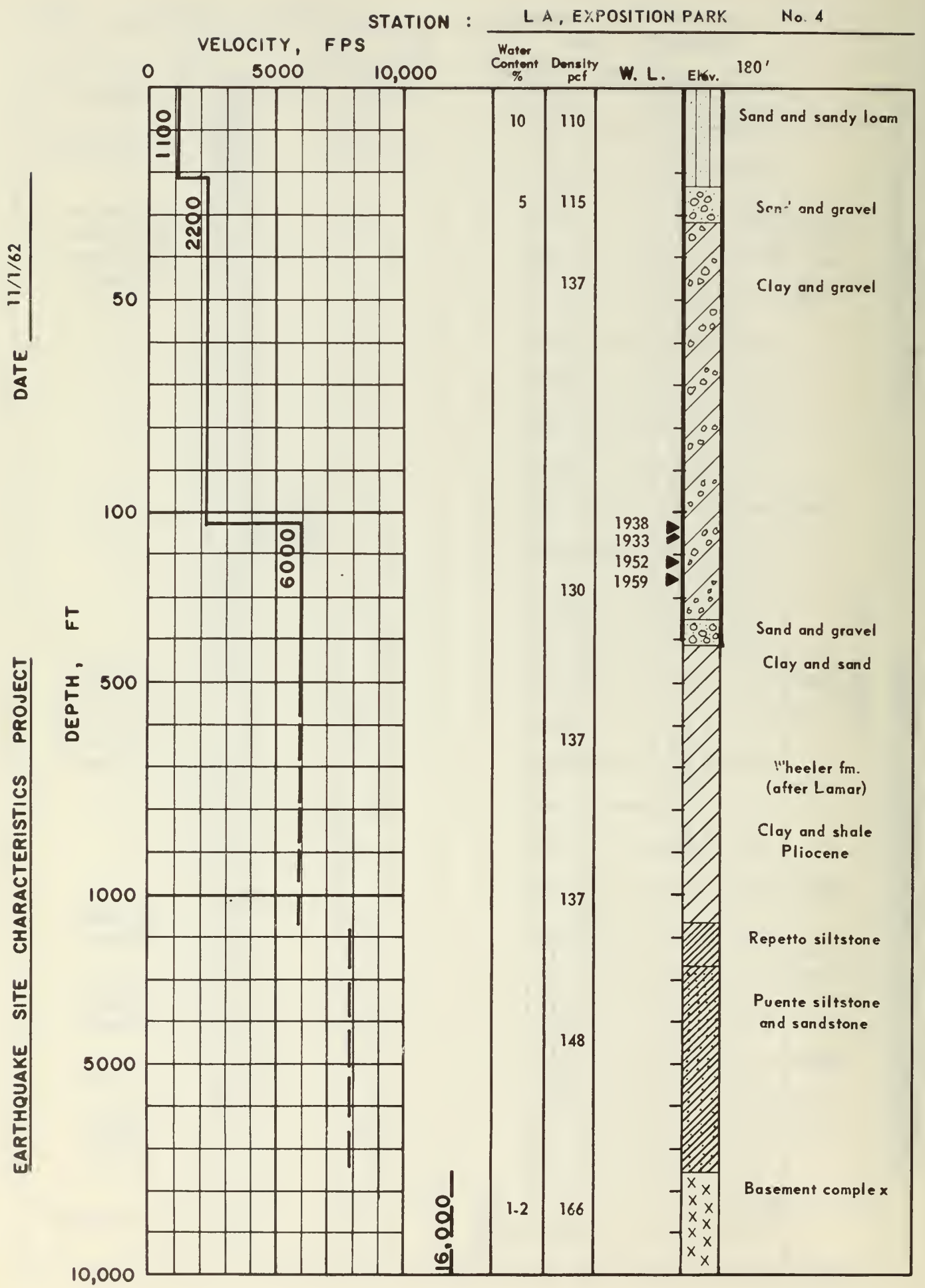
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10,000
Water Content %
Density pcf
W. L.
Elev.
180'
1100
2200
6000
16,000
10
110
Sand and sandy loam
5
115
Sand and gravel
137
Clay and gravel
1938
1933
1952
1959
130
Sand and gravel
Clay and sand
137
Wheeler fm. (after Lamar)
Clay and shale Pliocene
137
Repetto siltstone
Puente siltstone and sandstone
148
1-2
166
Basement complex
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
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EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

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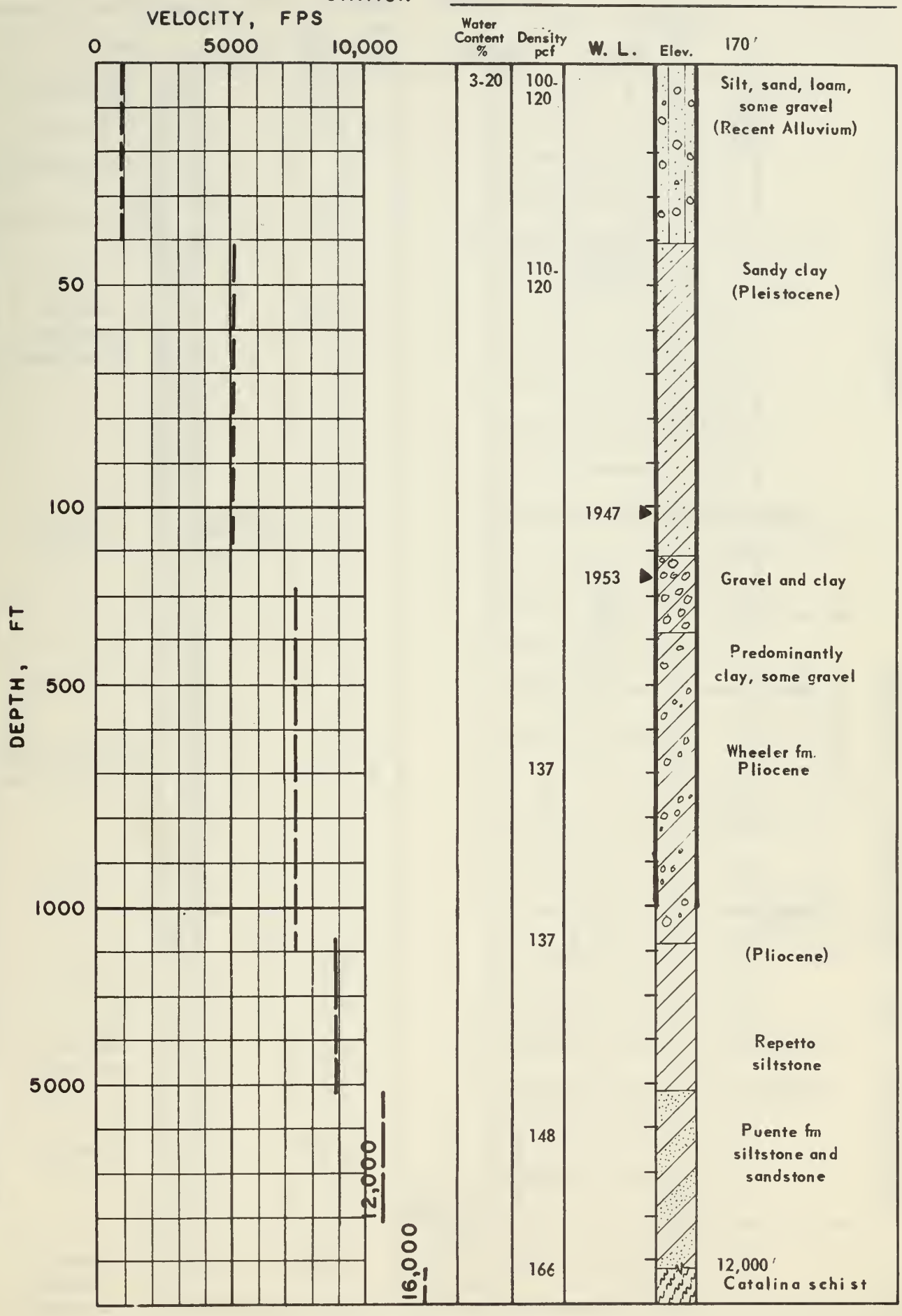

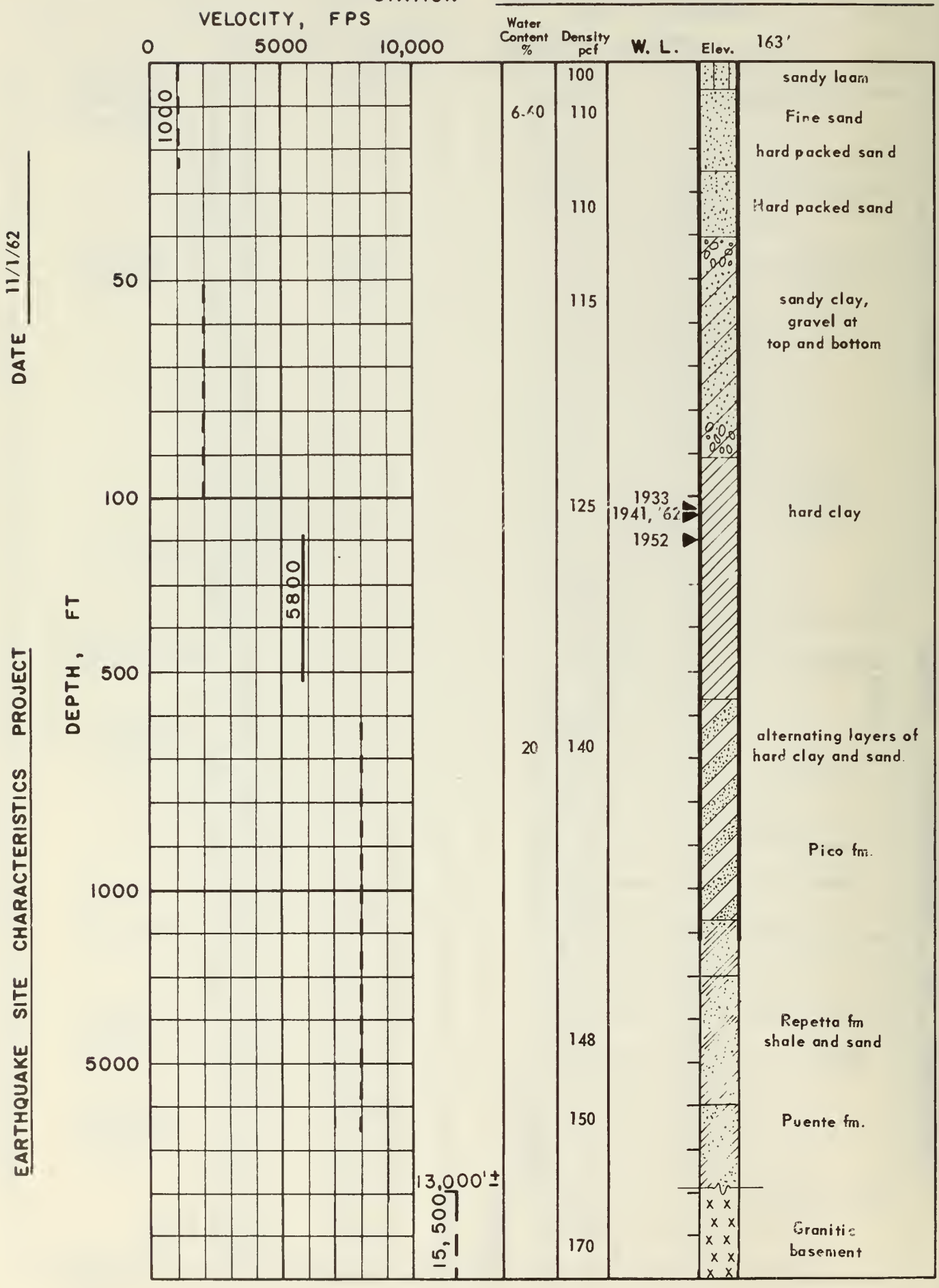
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10,000
Water Content %
Density pcf
W. L.
Elev.
163'
DATE 11/1/62
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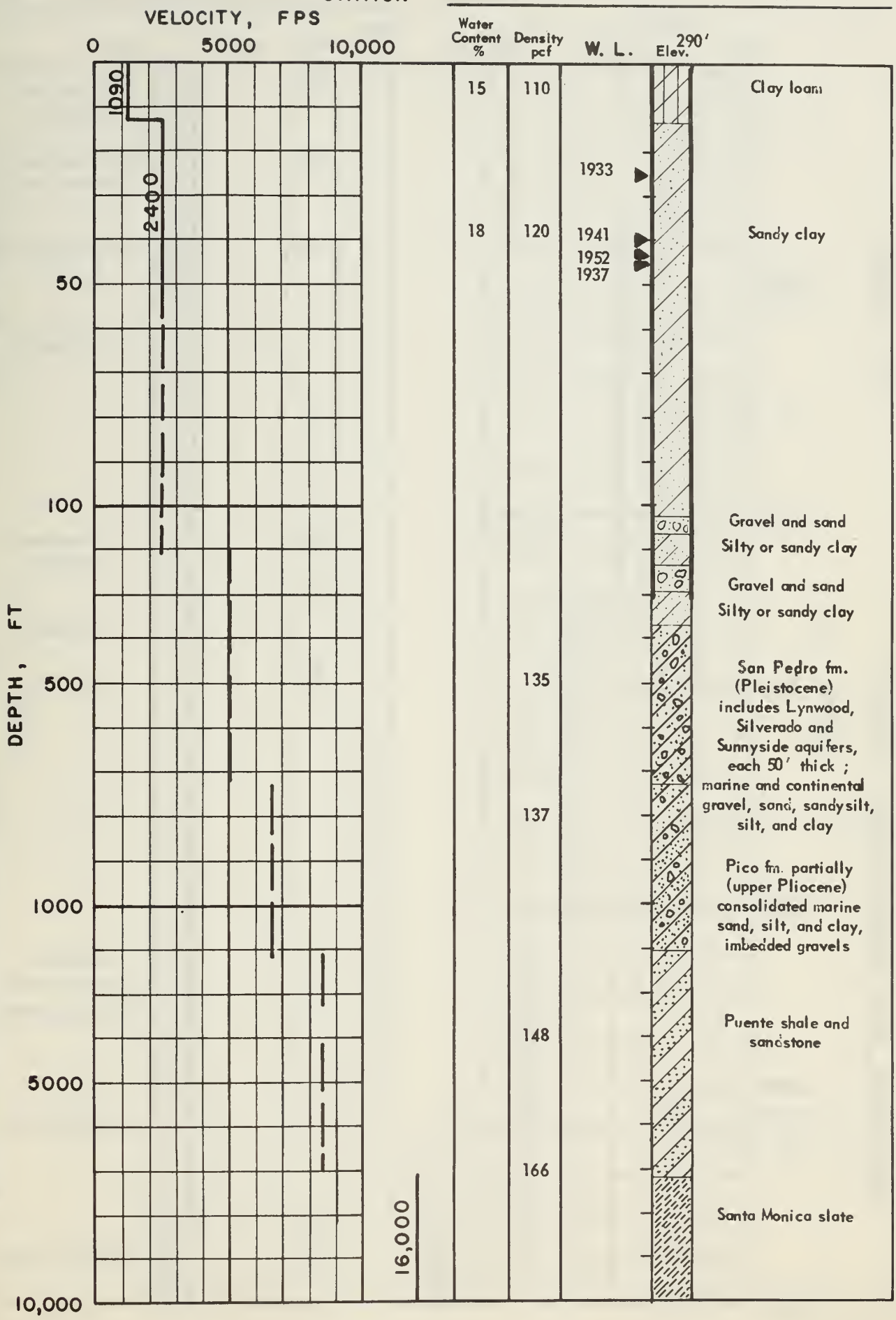
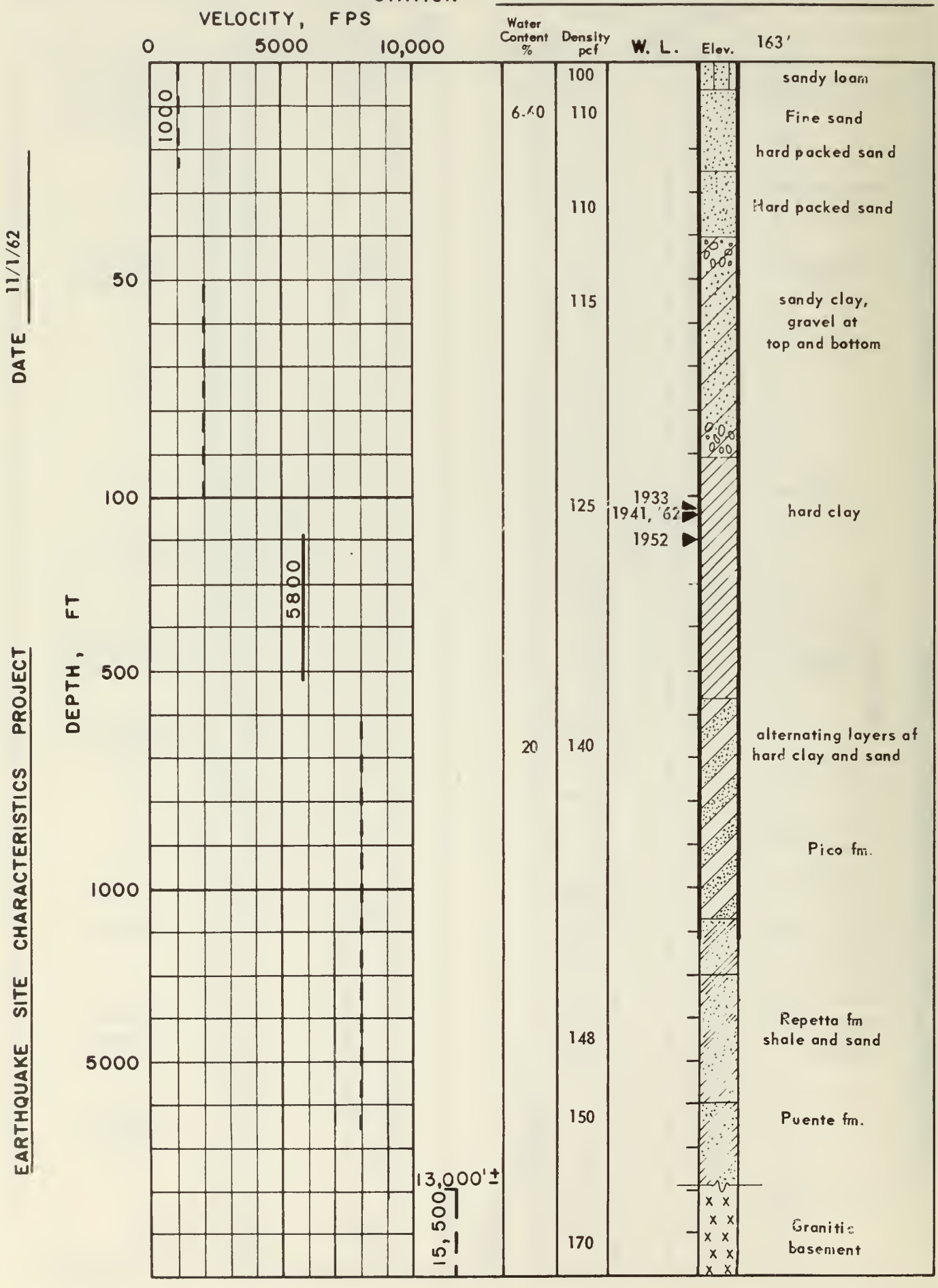
DEPTH, FT
50
100
500
1000
5000
1000
5800
13,000'±
15,500
6.40
20
100
110
110
115
125
140
148
150
170
1933
1941, '62
1952
sandy loam
Fine sand
hard packed sand
Hard packed sand
sandy clay, gravel at top and bottom
hard clay
alternating layers of hard clay and sand.
Pico fm.
Repetta fm shale and sand
Puente fm.
Granitic basement

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/42

STATION : L.A., HOLLYWOOD STORAGE No. 7

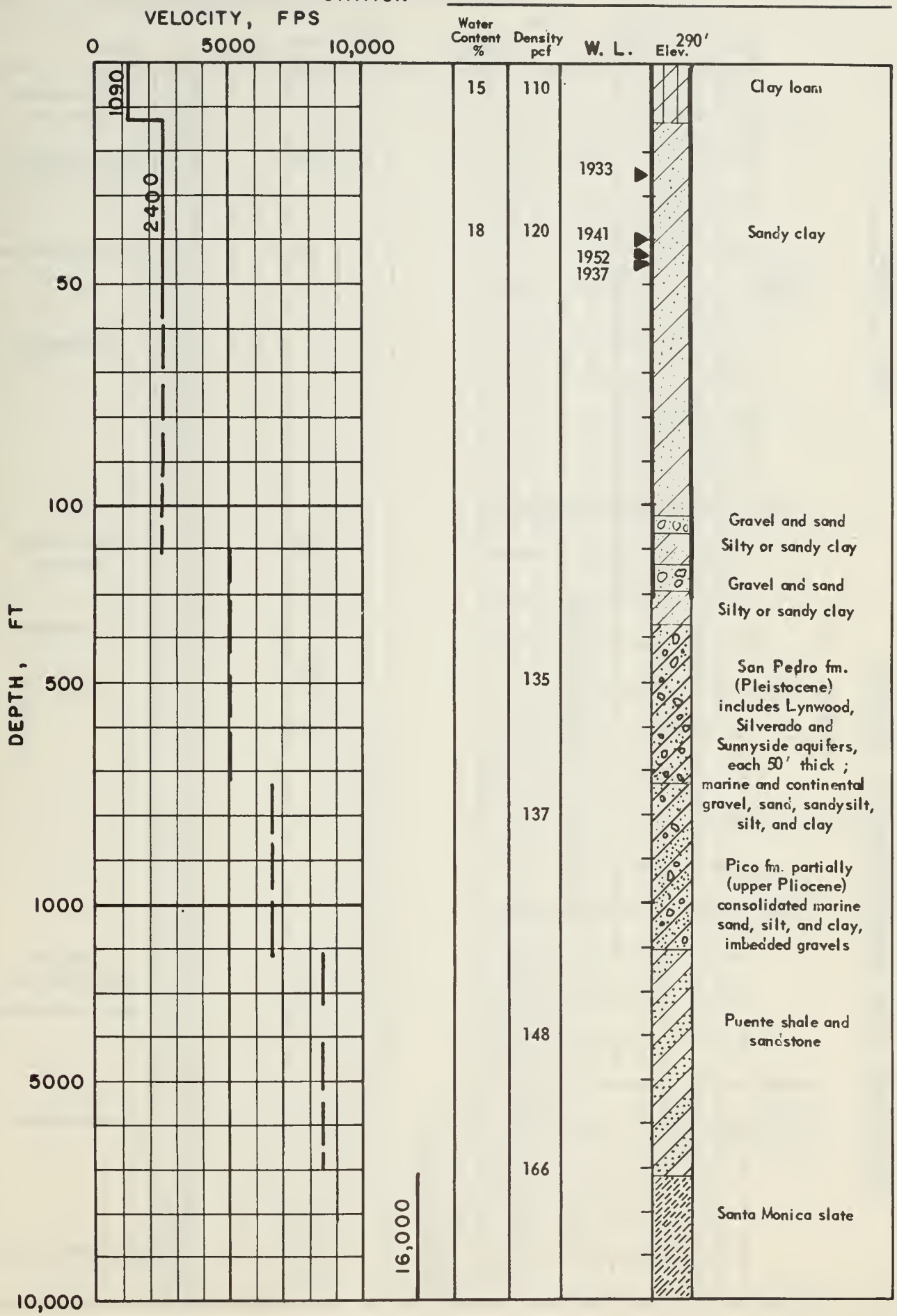



STATION : HUNTINGTON PARK CITY HALL No. 6
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev.
163'
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT
DEPTH, FT
50
100
500
1000
5000
1000
5800
13,000'±
15,500'
6.40
20
100
110
110
115
125
140
148
150
170
1933
1941, '62
1952
sandy loam
Fine sand
hard packed sand
Hard packed sand
sandy clay, gravel at top and bottom
hard clay
alternating layers of hard clay and sand
Pico fm.
Repetta fm shale and sand
Puente fm.
Granitic basement

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/42

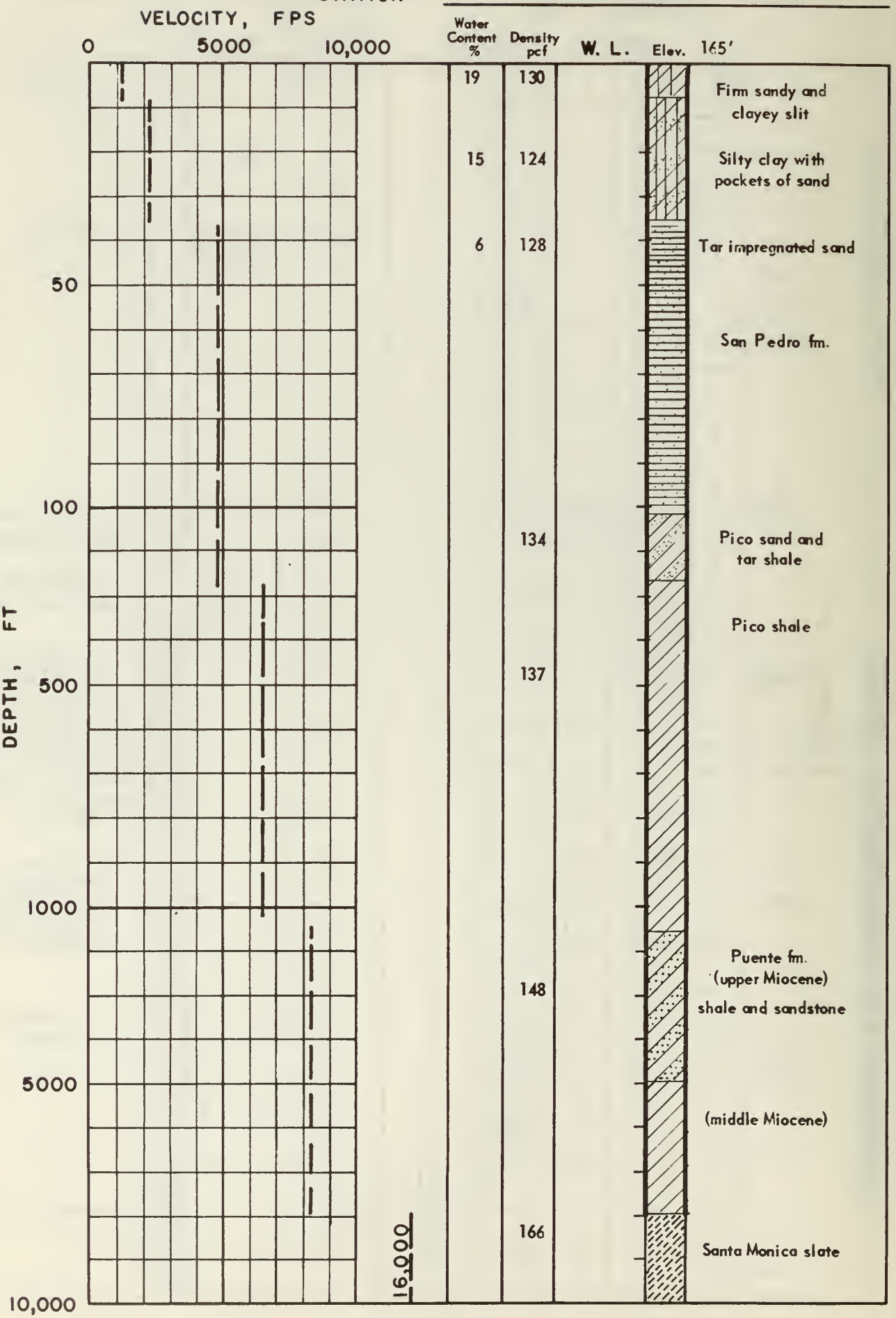
STATION : L.A., HOLLYWOOD STORAGE No. 7



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

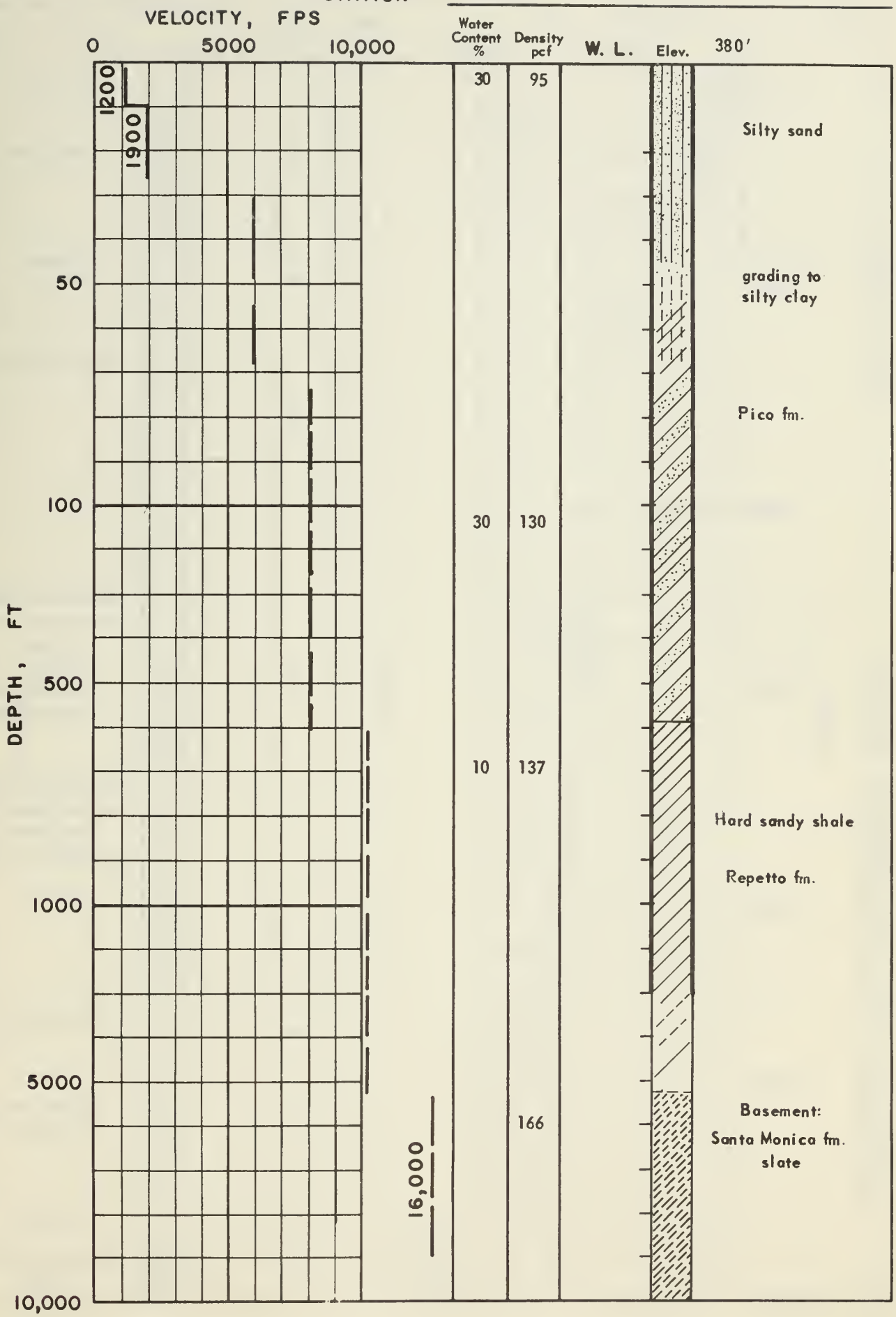
STATION : LOS ANGELES HANCOCK PARK No. 8



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : L A, WESTWOOD No 9

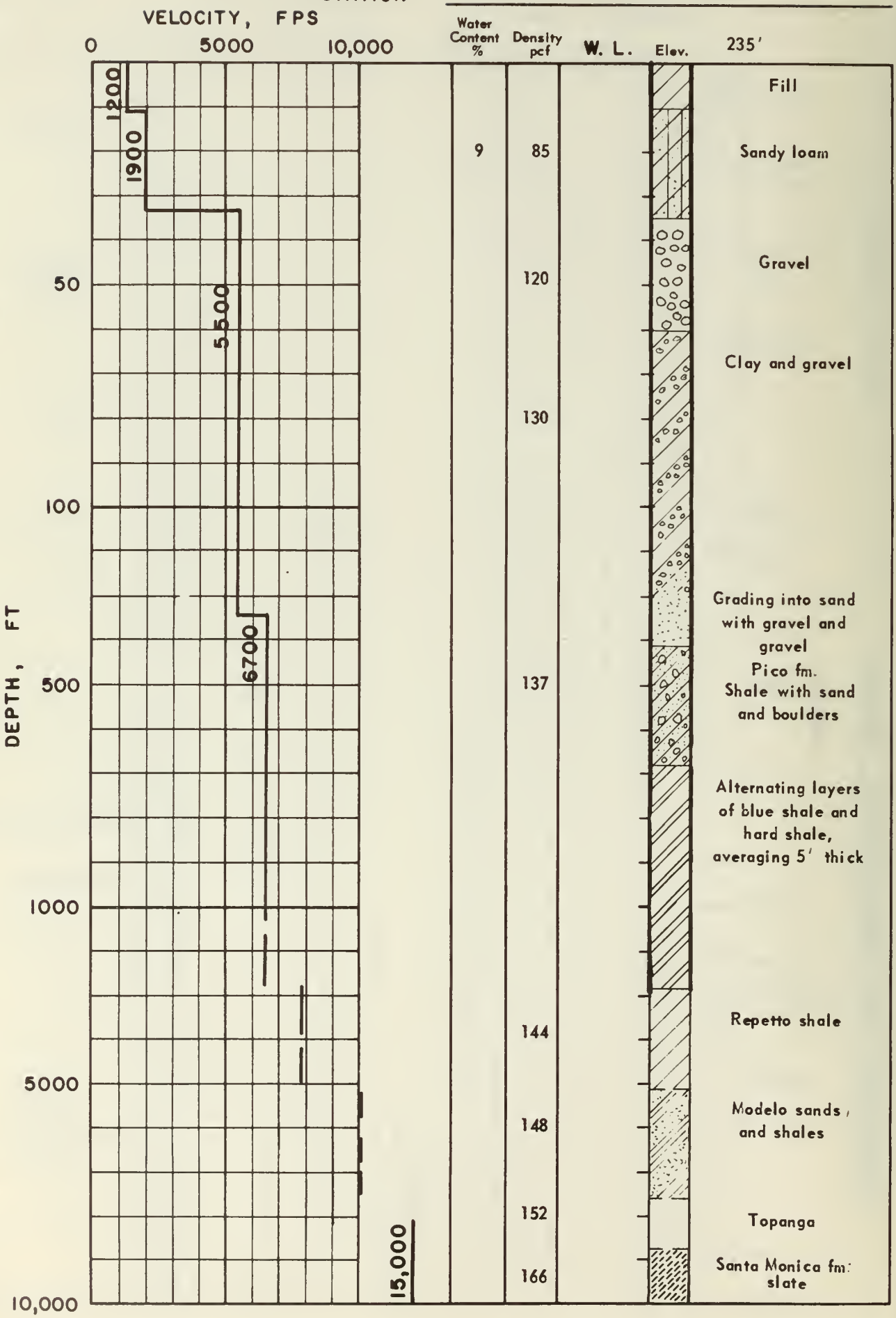


L A , WEST L A. PUBLIC LIBRARY

STATION : No. 10

EARTHQUAKE SITE CHARACTERISTICS PROJECT

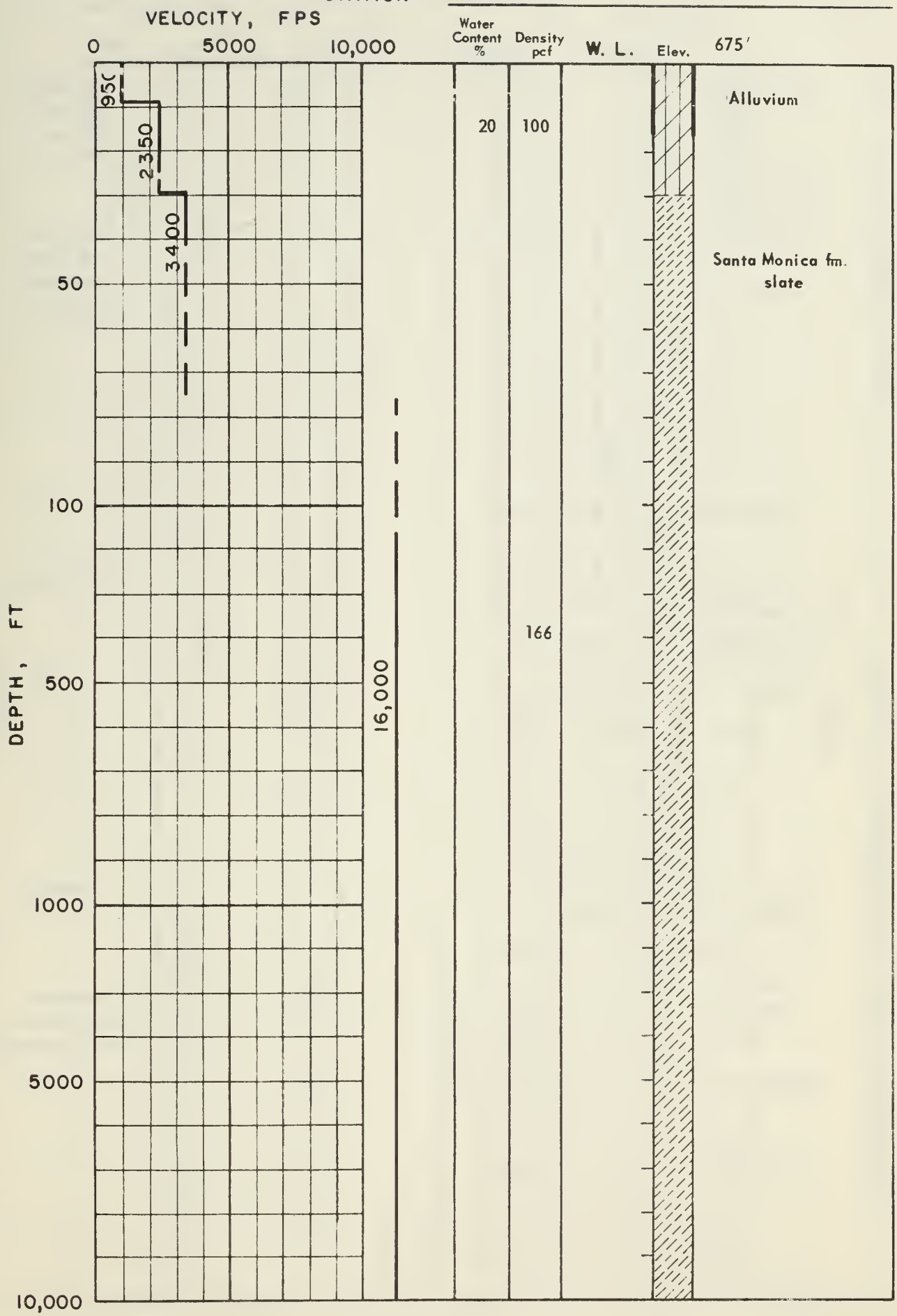
DATE 11/1/62



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

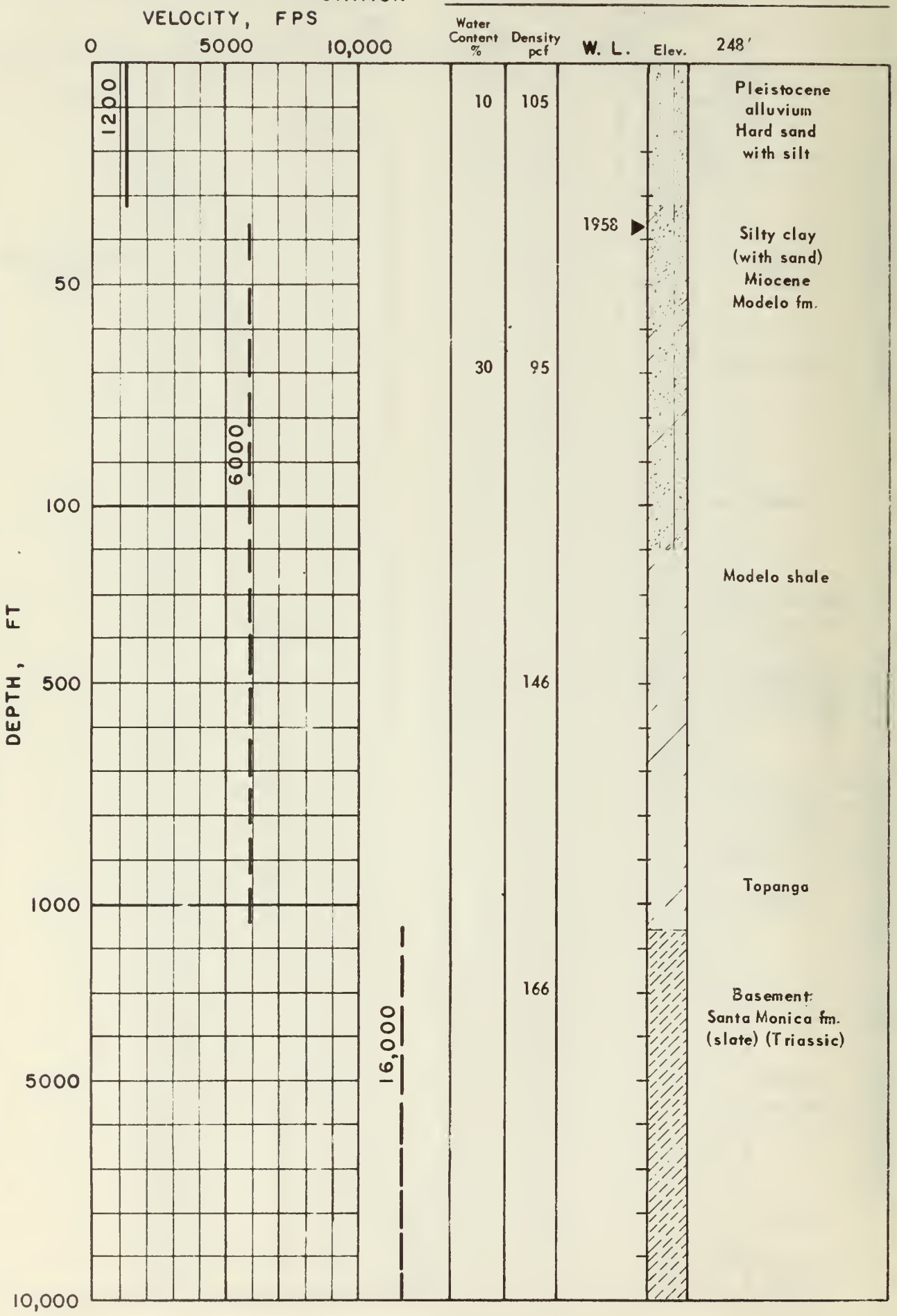
STATION : L A BRENTWOOD DUKE RES No 11



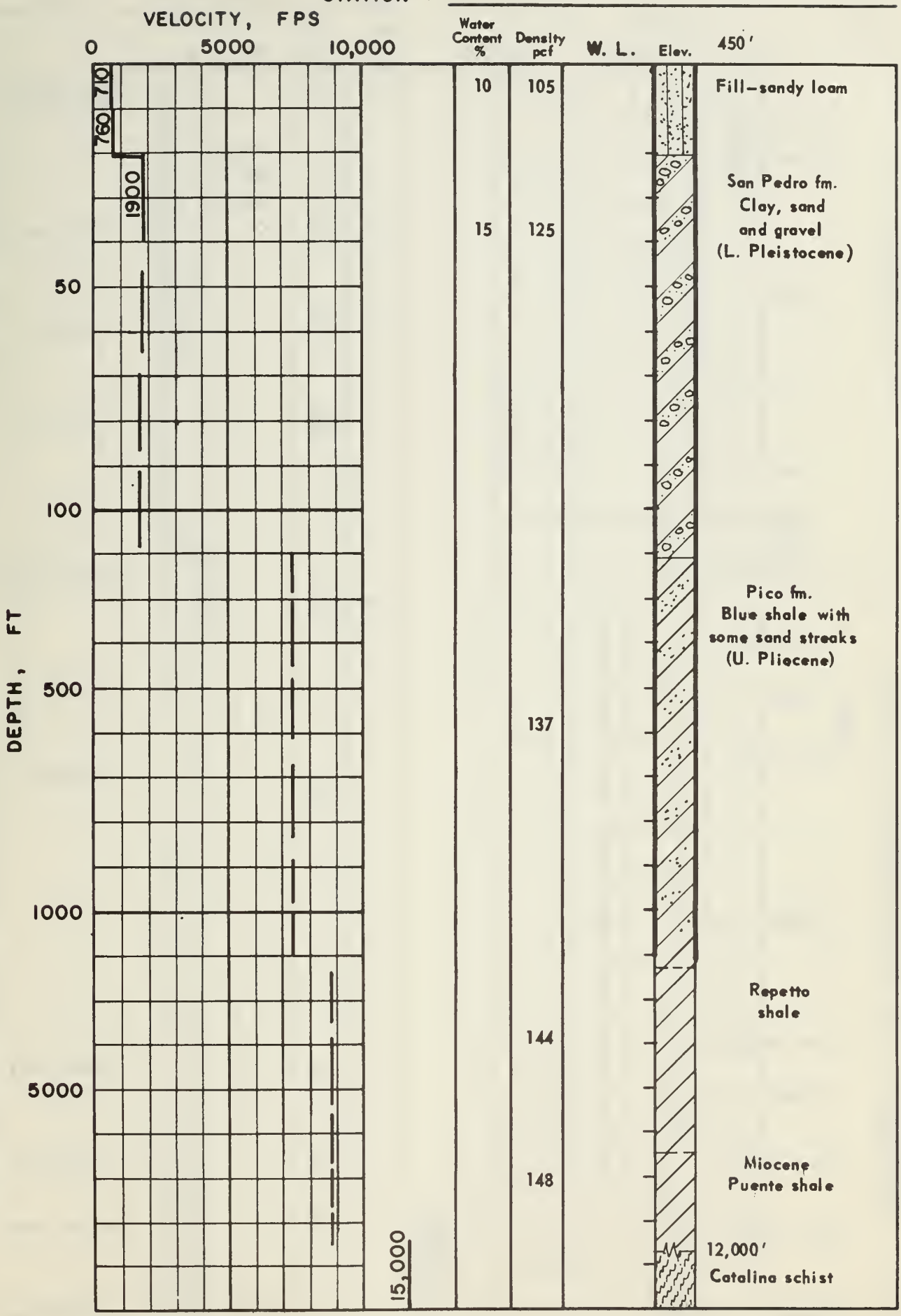
EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : L A., PACIFIC PALISADES No 12



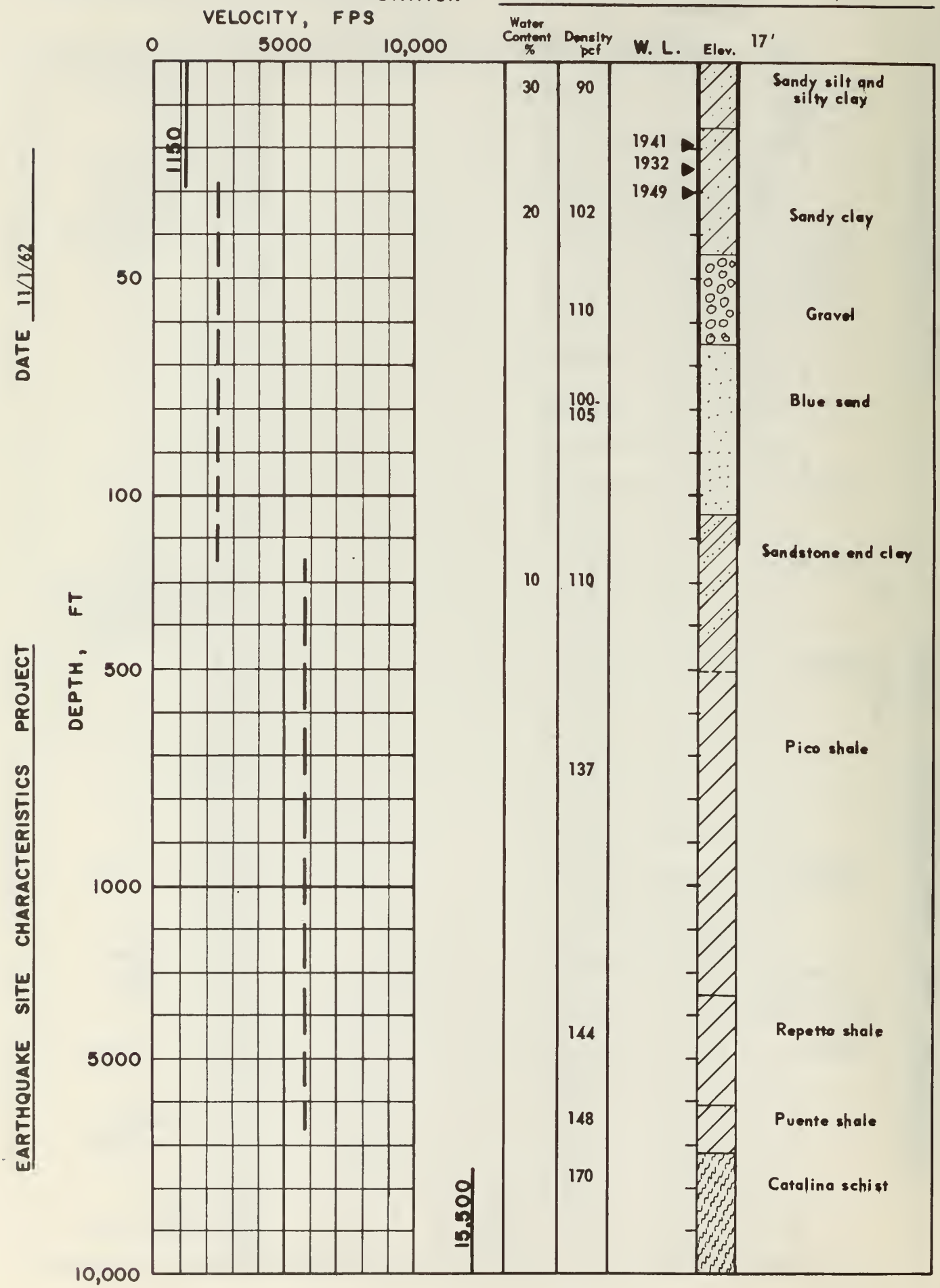
STATION : L. A., WINDSOR HILLS ELEM. SCHOOL No. 13



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : L.A., PLAYA ELEM. SCHOOL No. 14



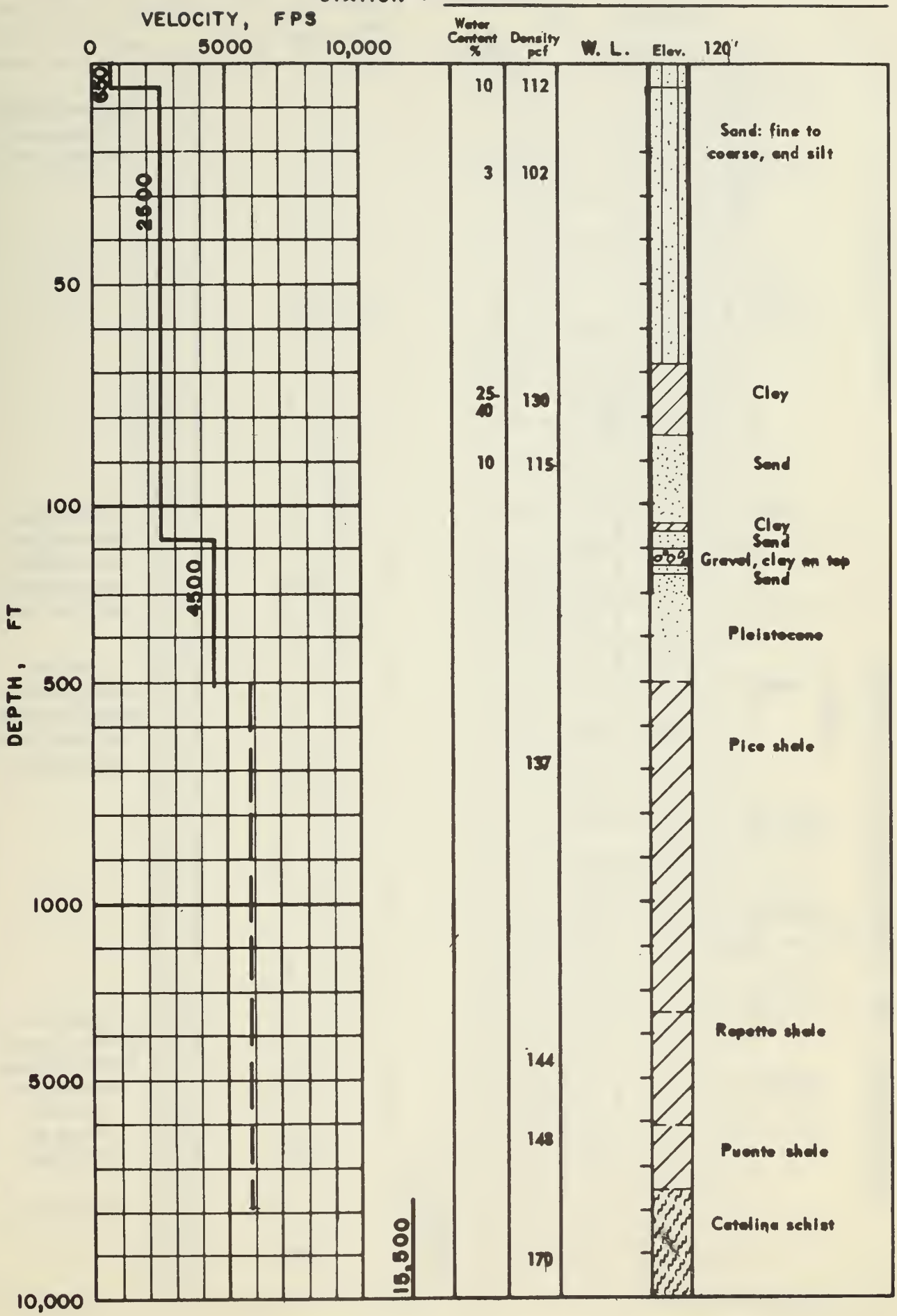
DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

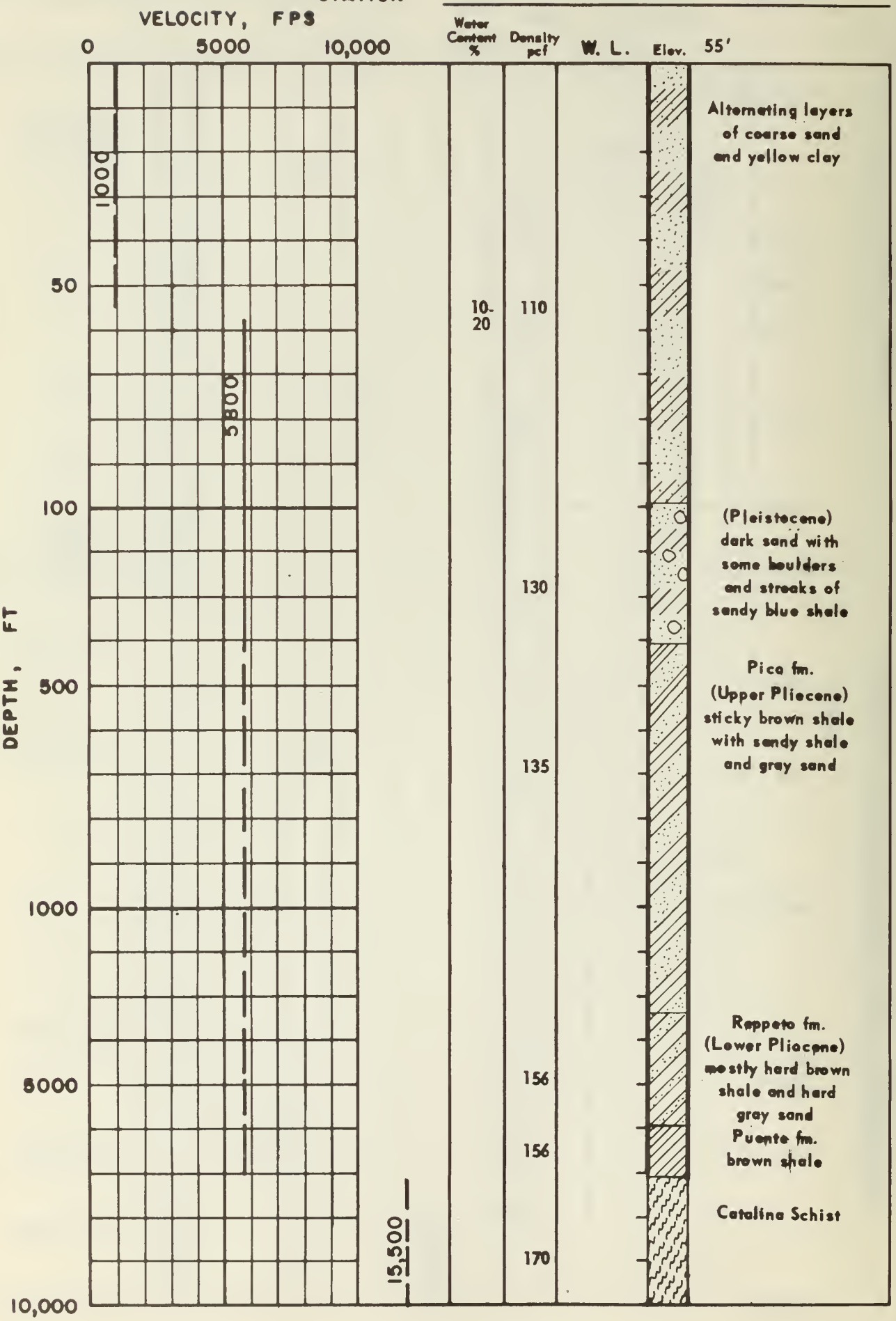
STATION : L.A., WESTCHESTER, LEEDS RES. No. 15



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

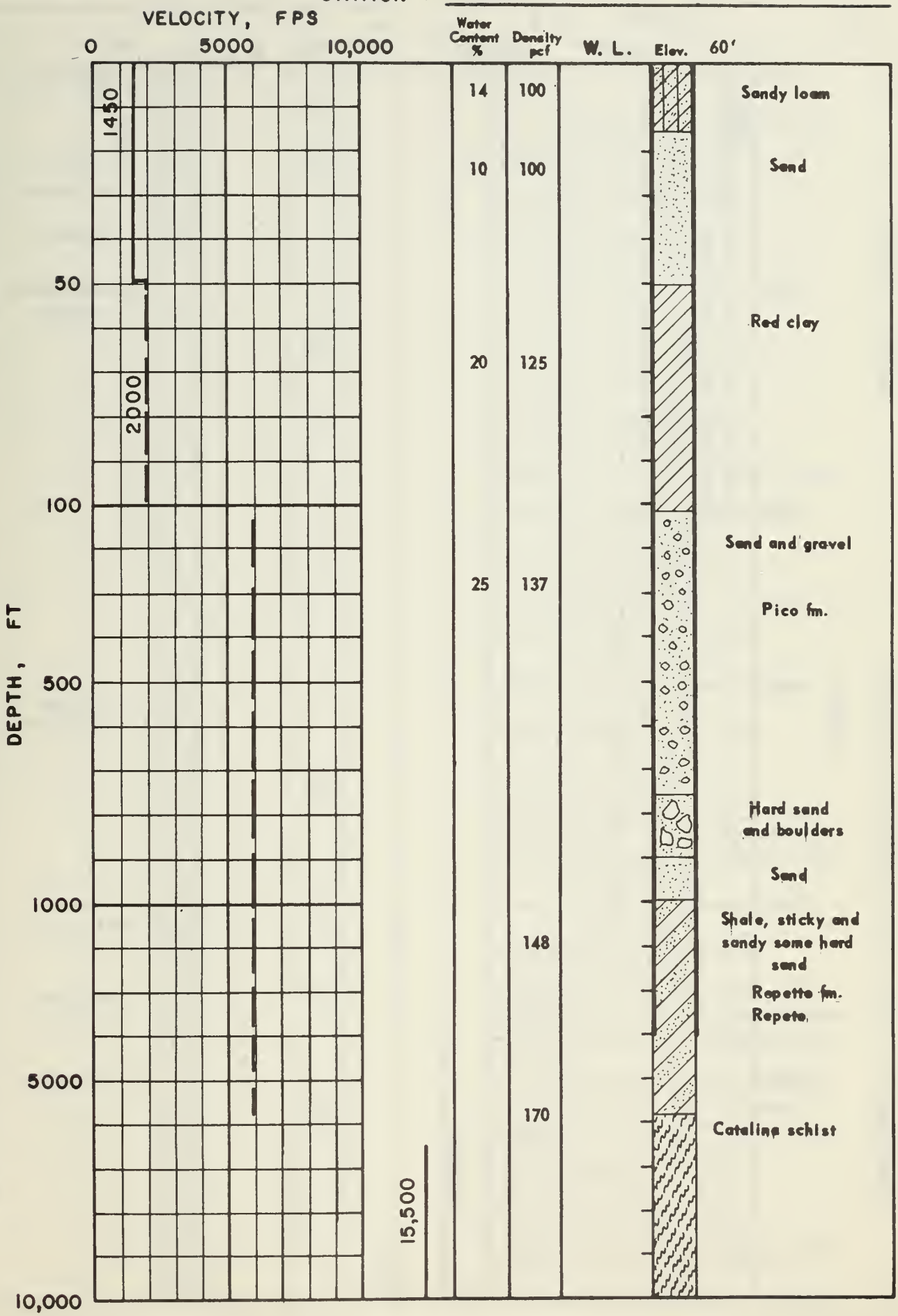
STATION : L.A., HYPERION PLANT No. 16

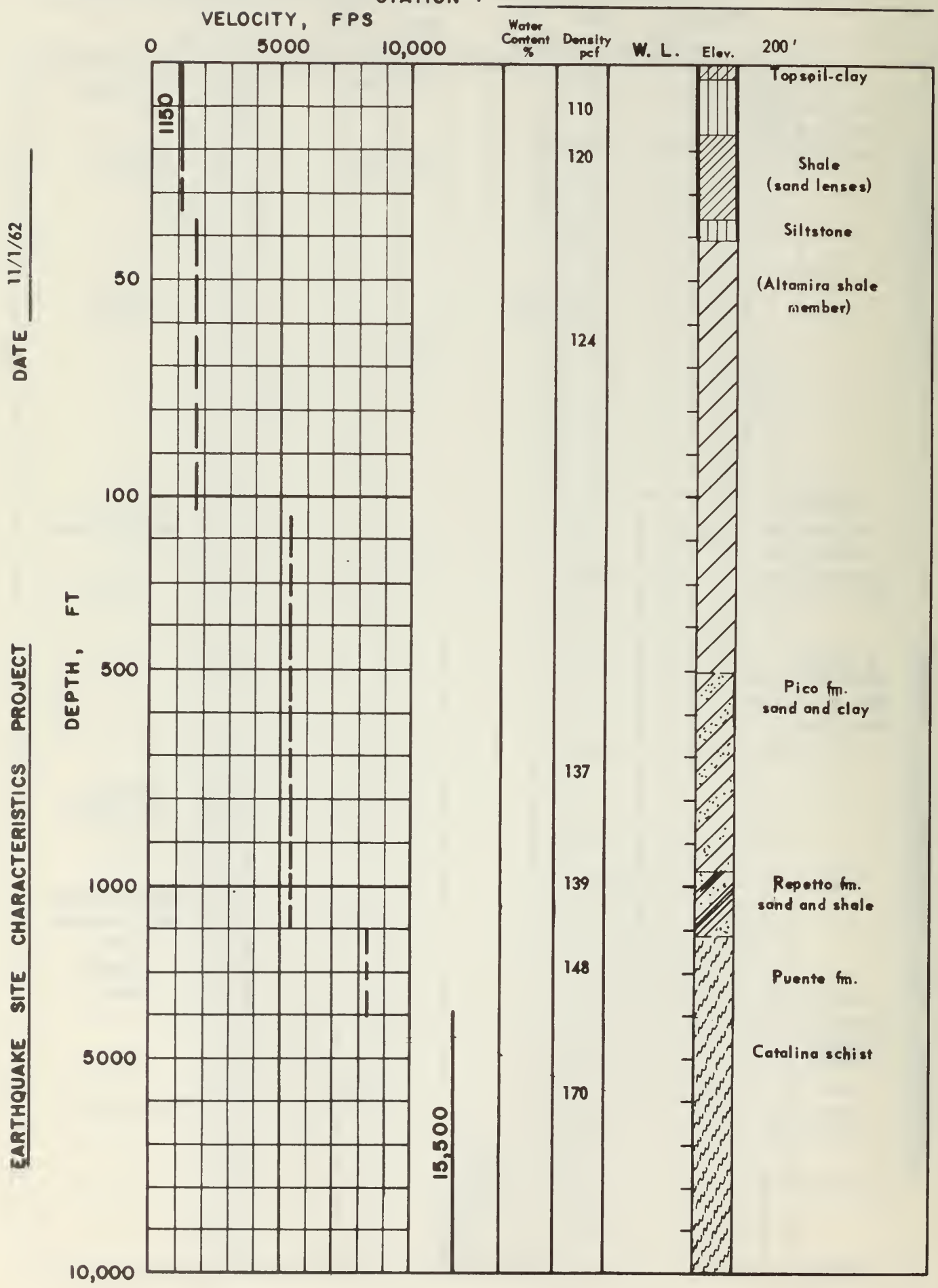


EARTHQUAKE SITE CHARACTERISTICS PROJECT

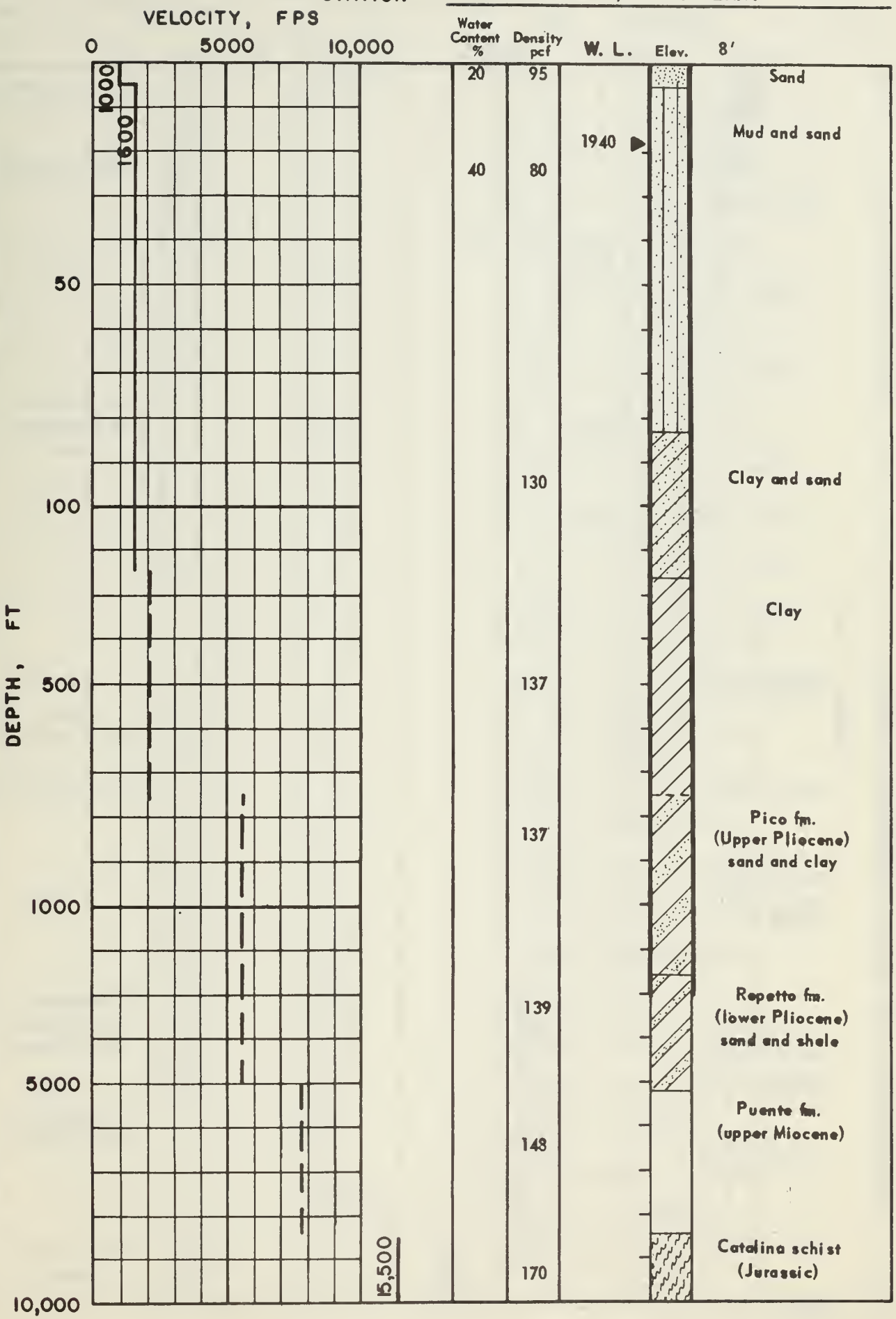
DATE 11/1/62

STATION : LOS ANGELES, HARBOR CITY No. 17




STATION : SAN PEDRO No. 18
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev.
200'
1150
15,500
110
120
124
137
139
148
170
Topsoil-clay
Shale
(sand lenses)
Siltstone
(Altamira shale member)
Pico fm.
sand and clay
Repetto fm.
sand and shale
Puente fm.
Catalina schist
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

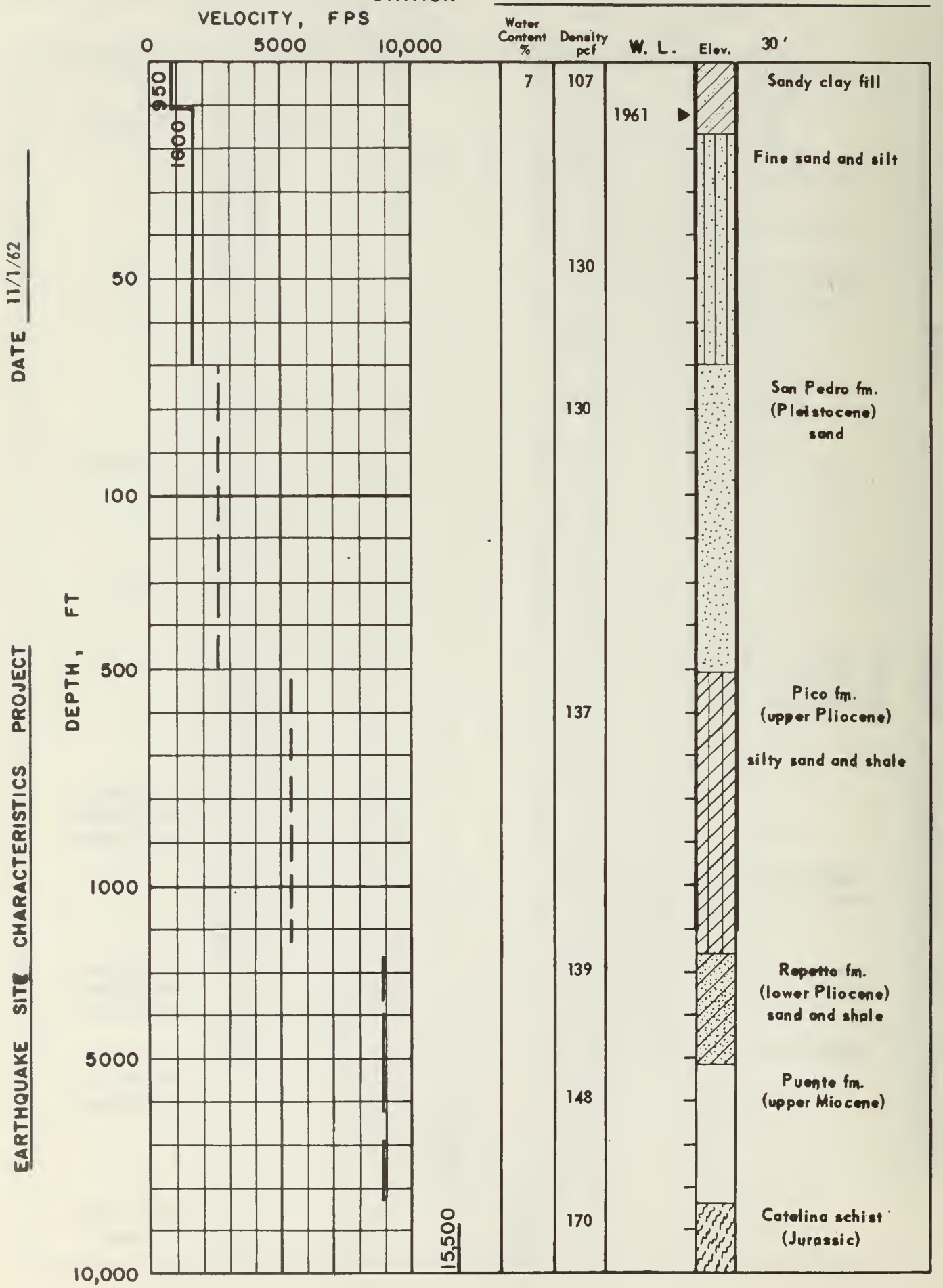
STATION : LONG BEACH, EDISON PLANT No. 19



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

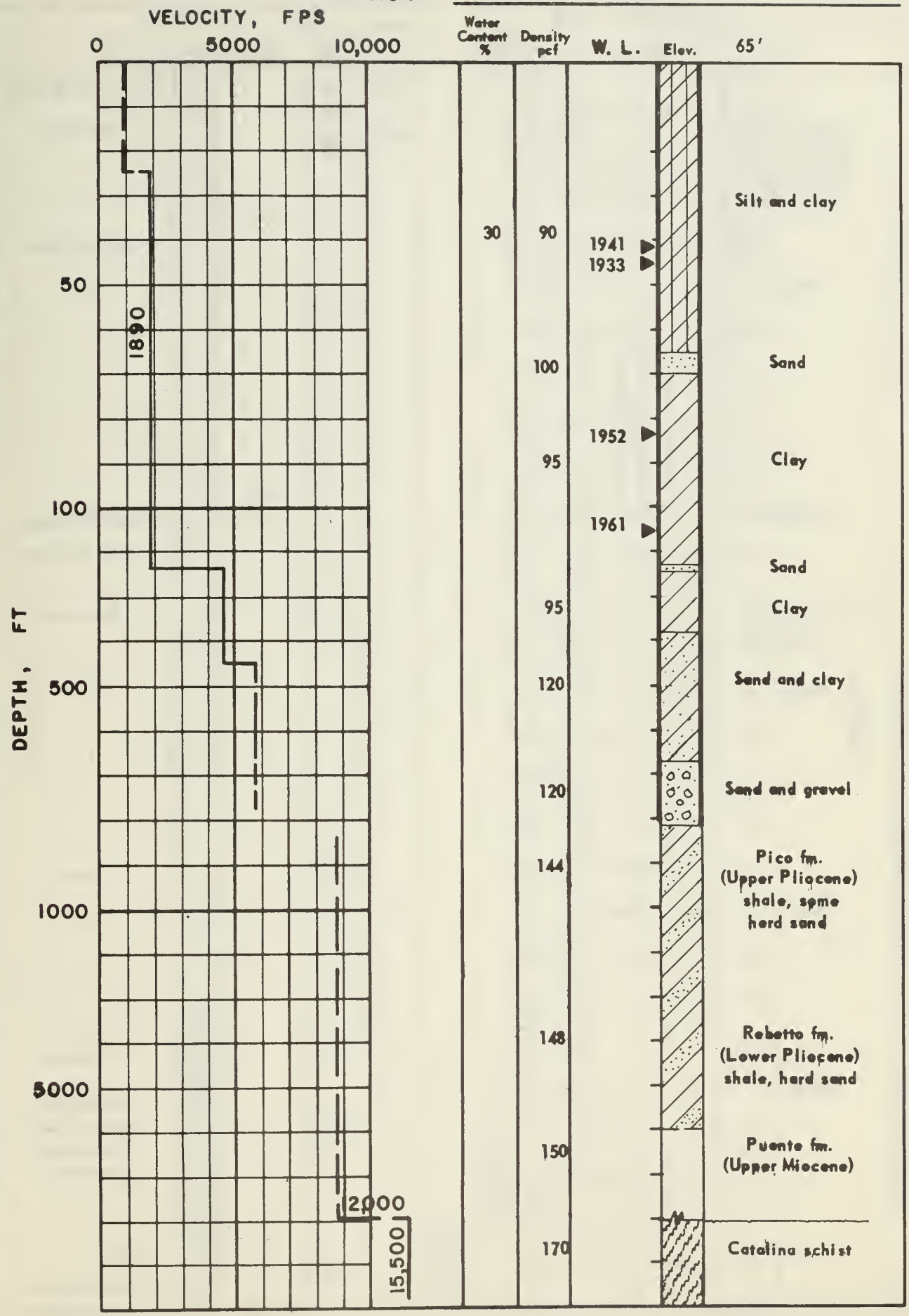
STATION : LONG BEACH, UTILITIES BLDG. No. 20



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

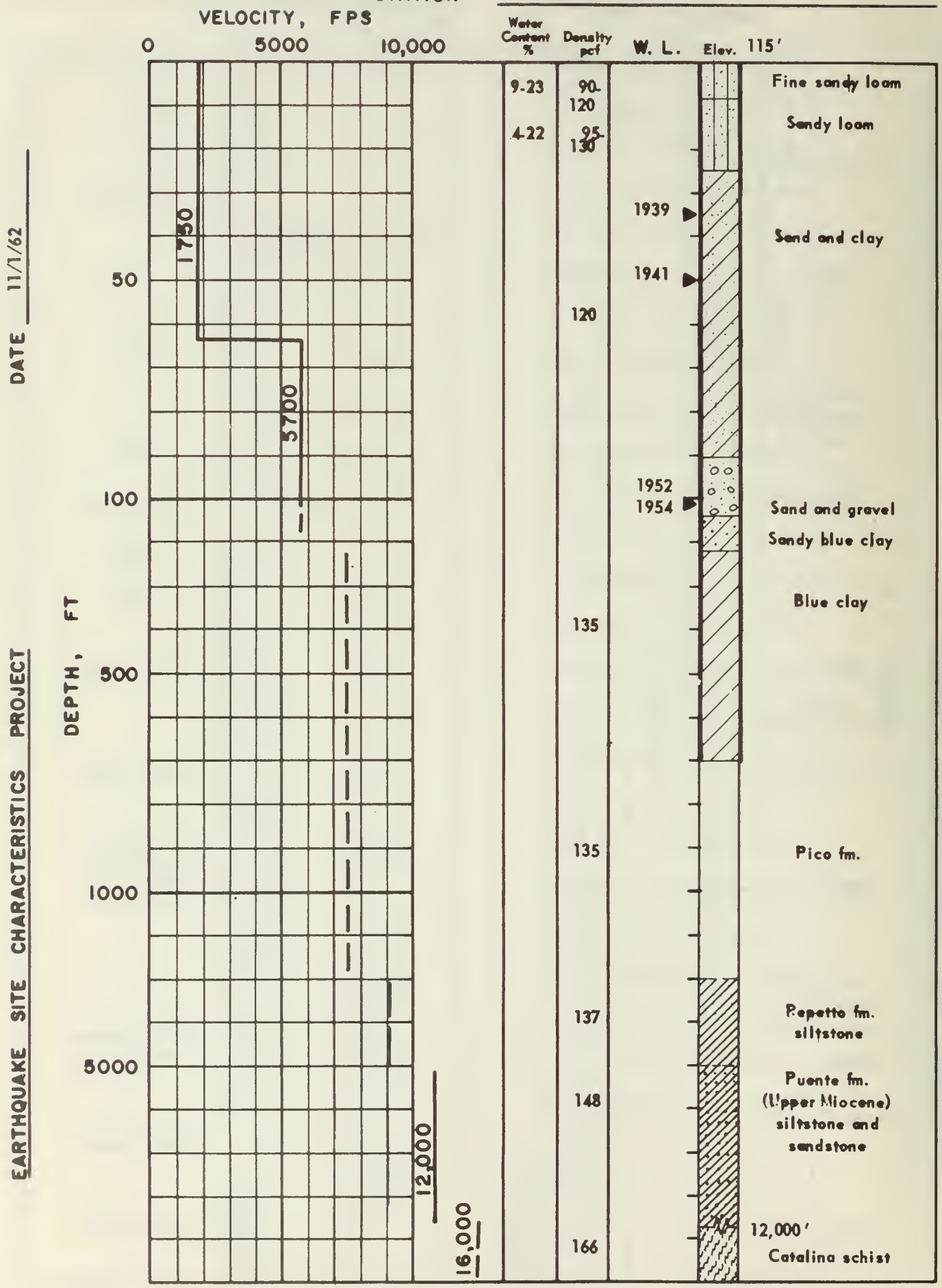
STATION : COMPTON SCHOOL BLDG. No. 21



DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

STATION : SOUTHGATE HIGH SCHOOL No. 22



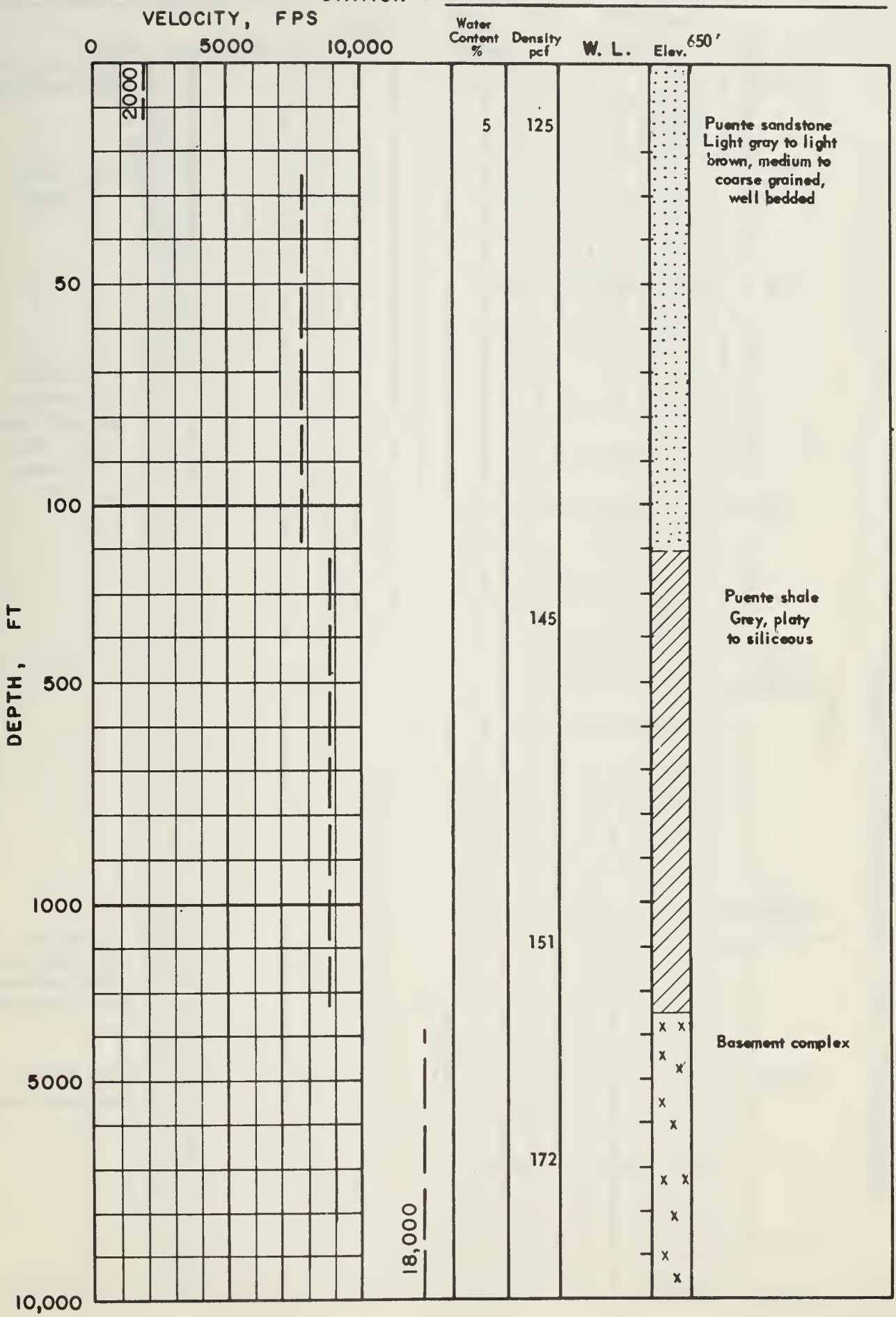
DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

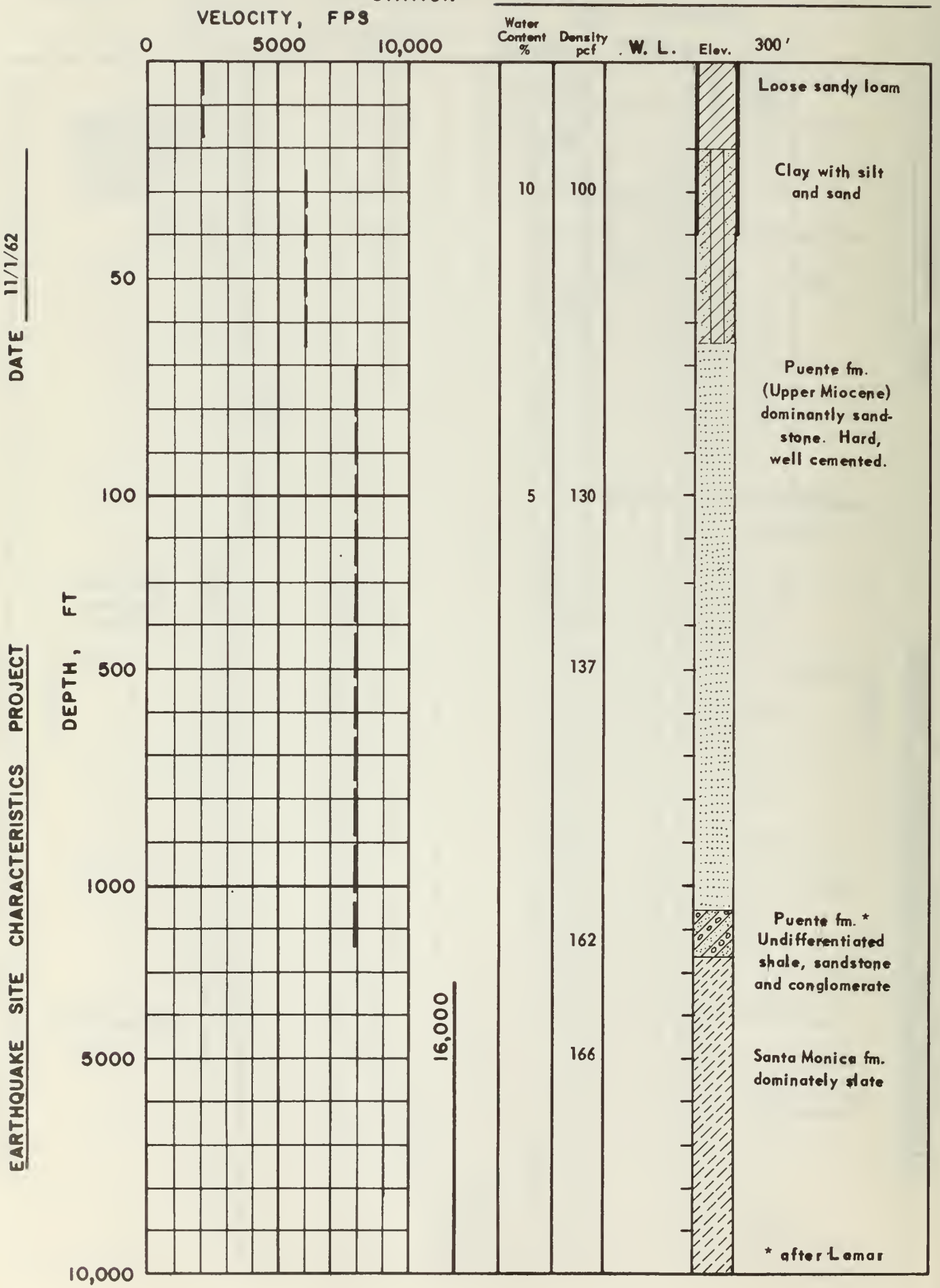
STATION : LOS ANGELES, HIGHLAND PARK No. 23



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

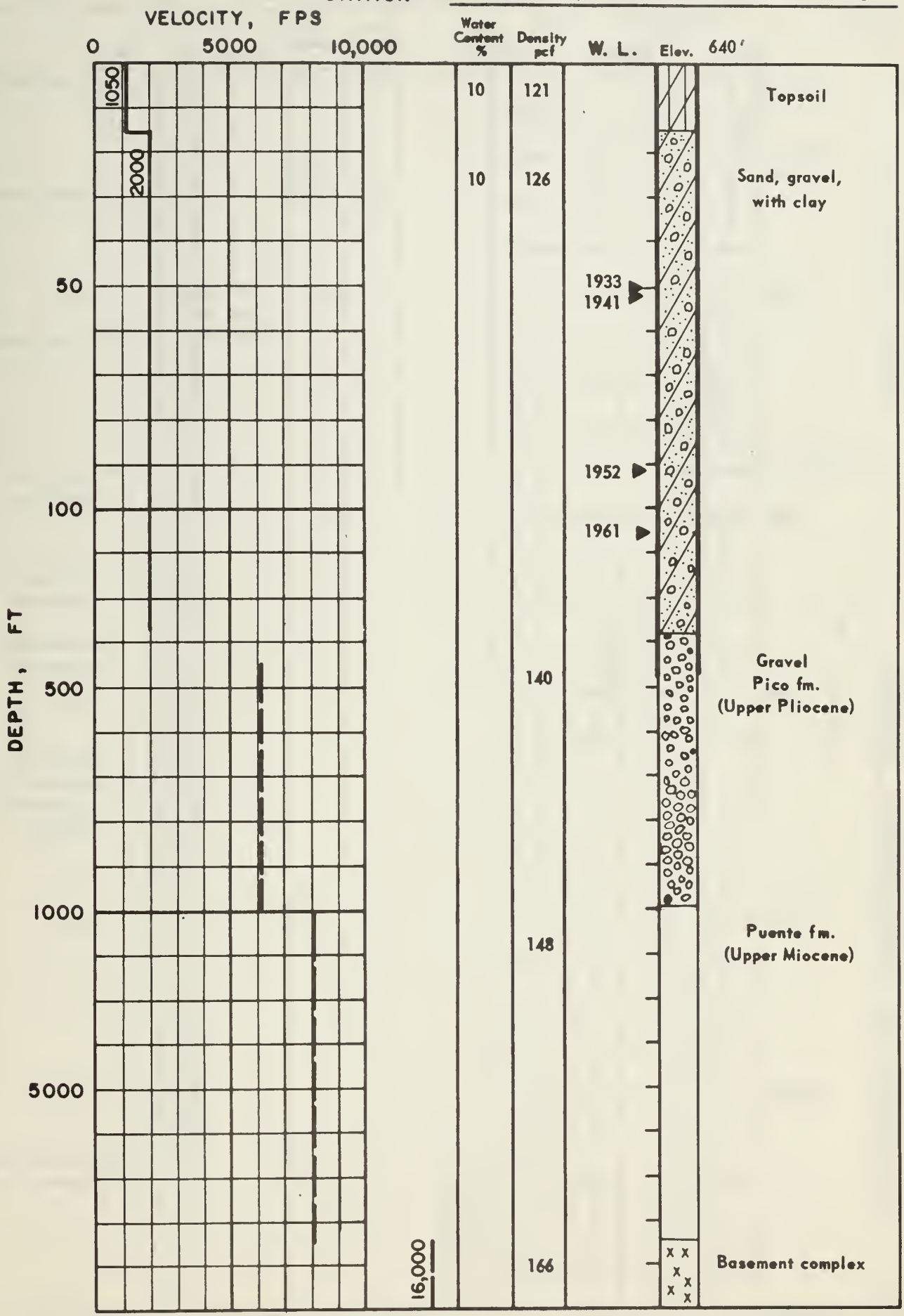
STATION : L. A., ELYSIAN HTS. SCHOOL No. 24

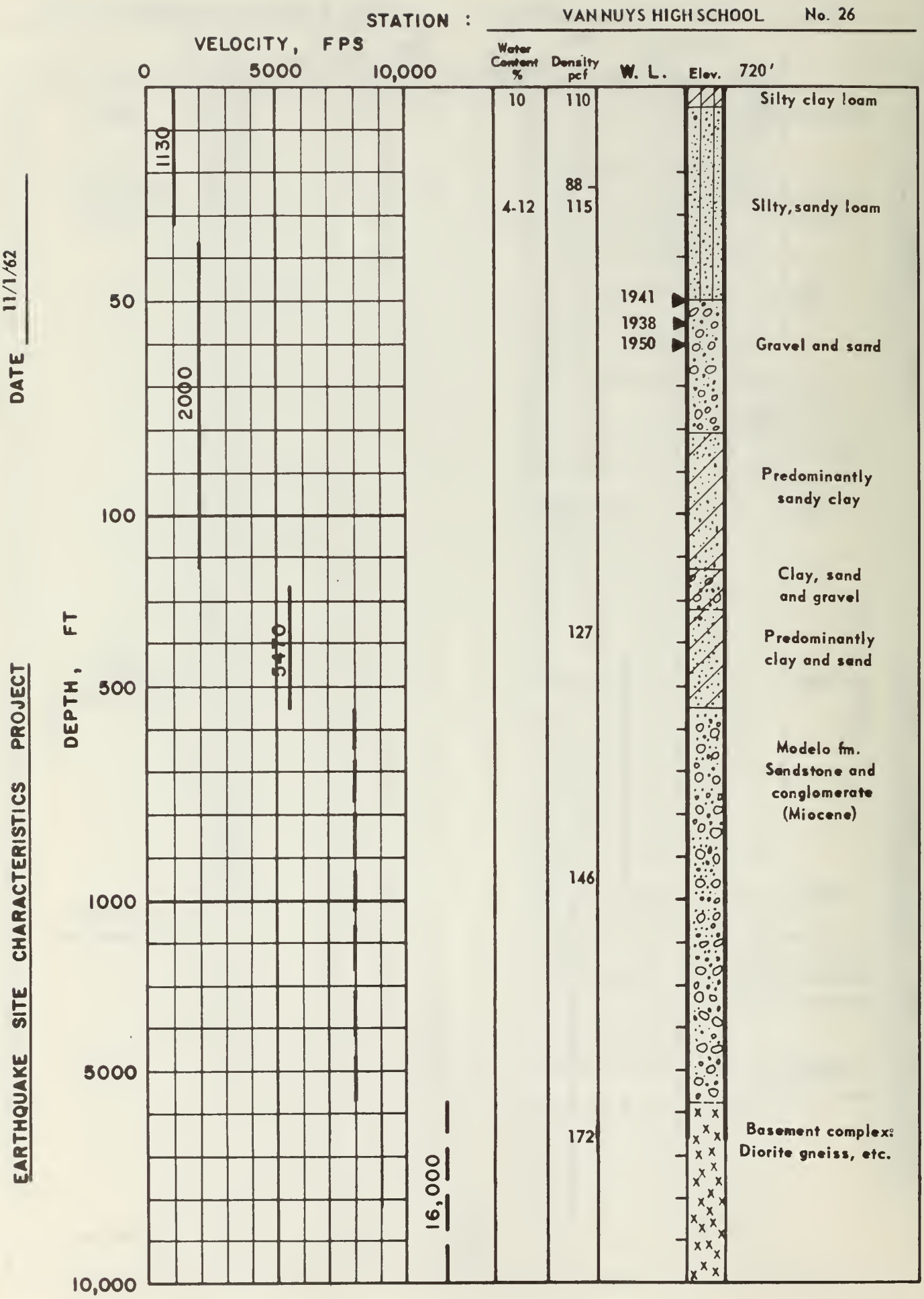


EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : GLENDALE, HOOVER HIGH SCHOOL No. 25

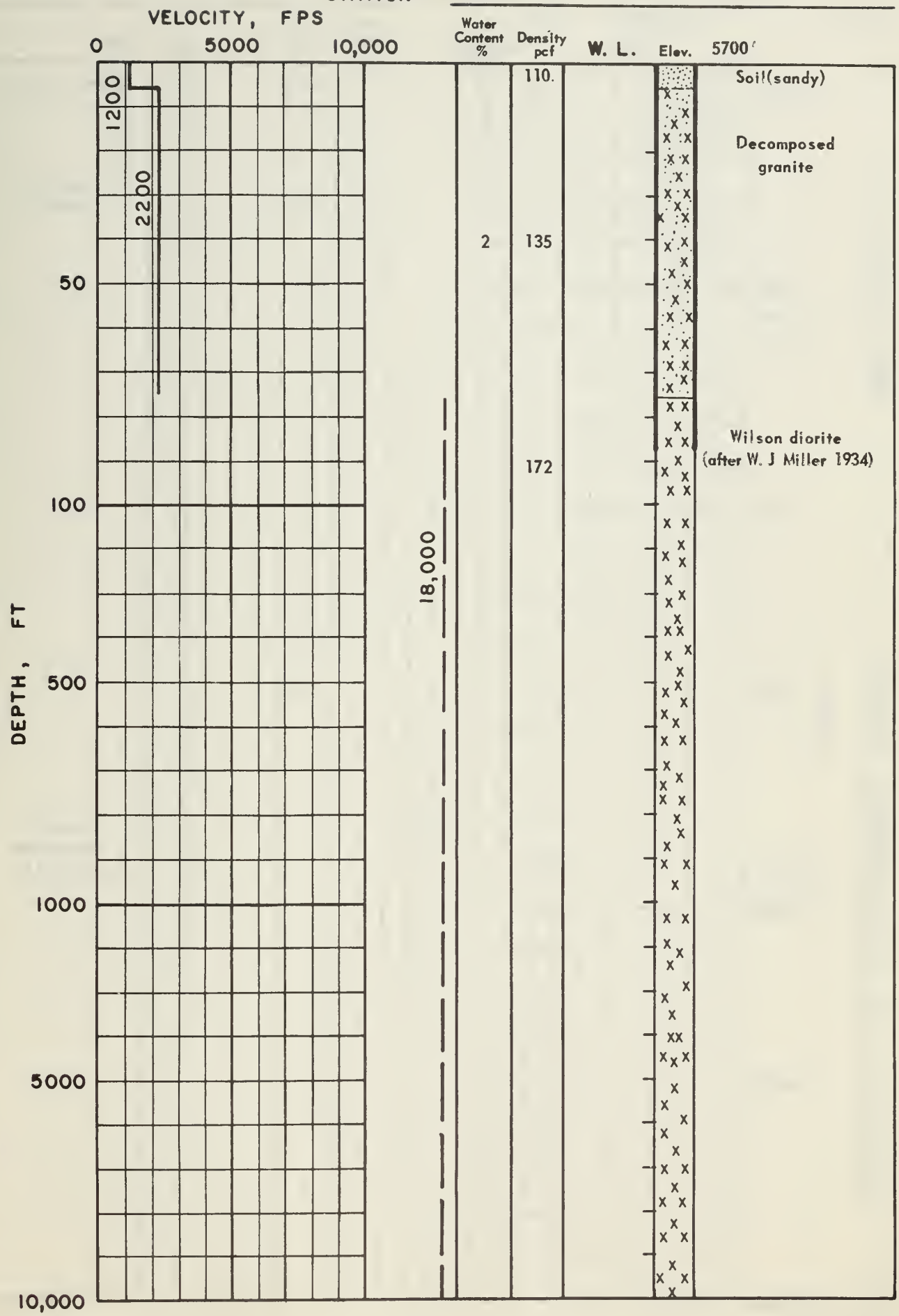



STATION : VAN NUYS HIGH SCHOOL No. 26
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 720'
1130
2000
3470
16,000
10
110
88
4-12
115
127
146
172
1941
1938
1950
Silty clay loam
Silty, sandy loam
Gravel and sand
Predominantly sandy clay
Clay, sand and gravel
Predominantly clay and sand
Modelo fm. Sandstone and conglomerate (Miocene)
Basement complex: Diorite gneiss, etc.
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

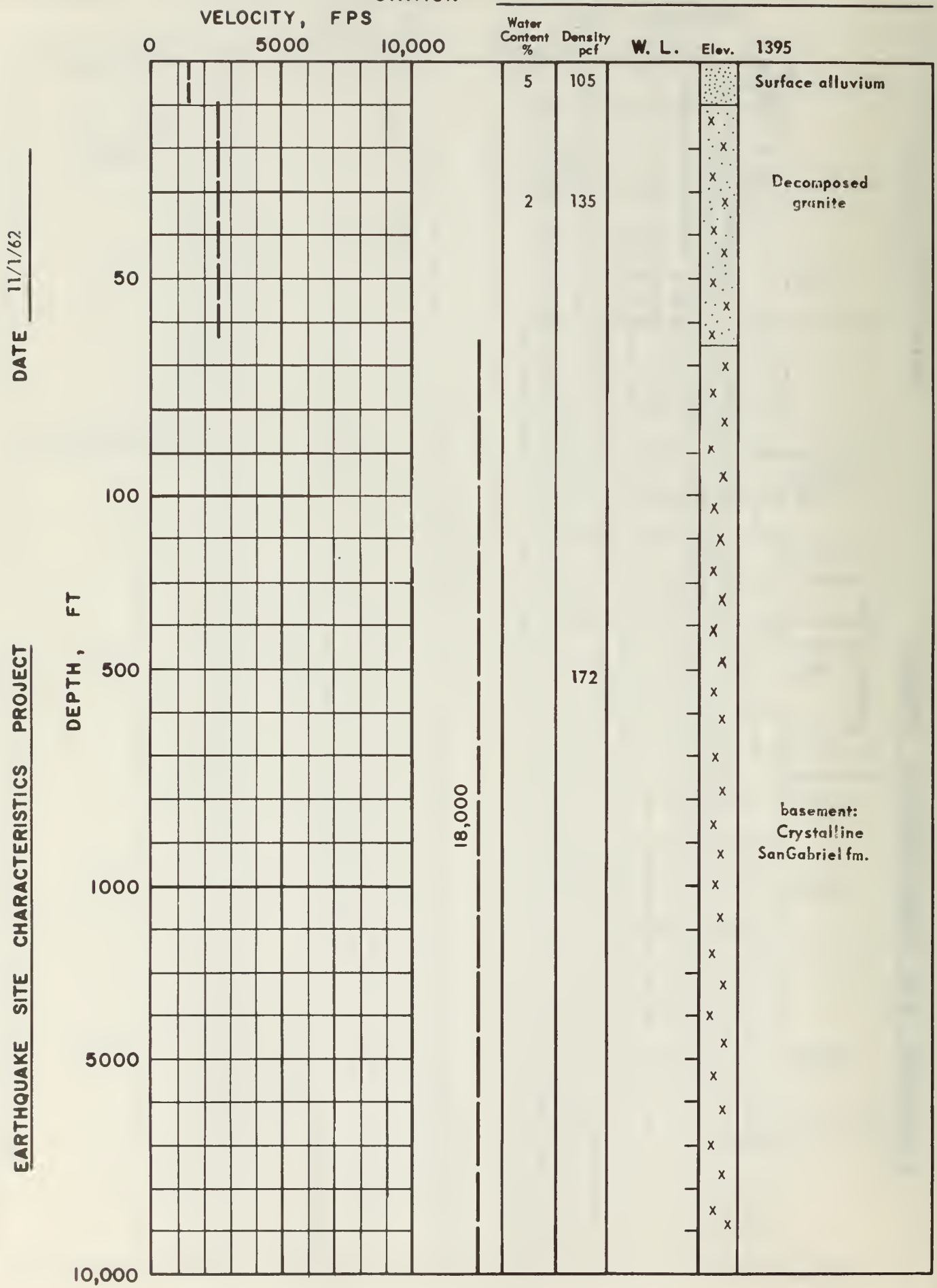
EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : MOUNT WILSON OBSERVATORY No. 27



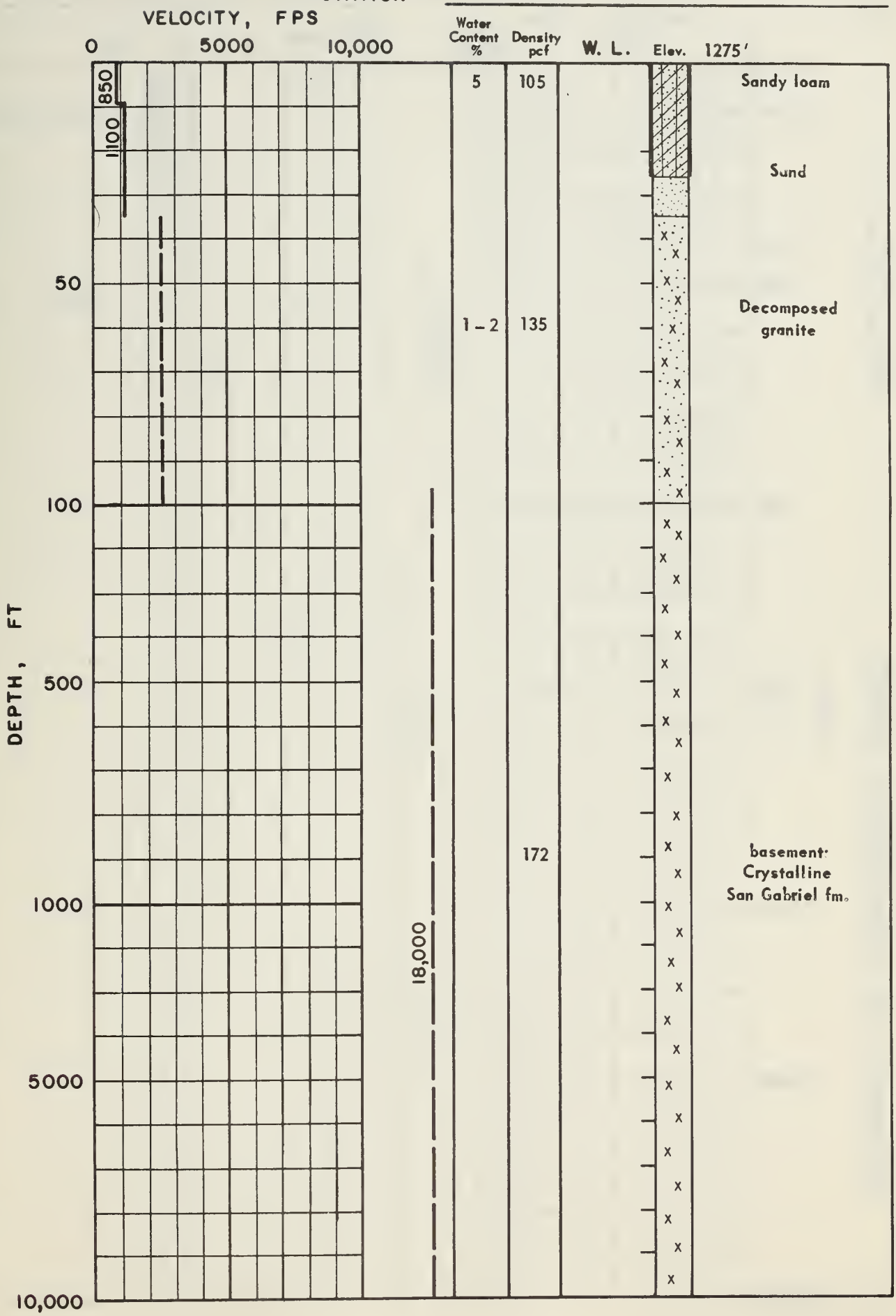
STATION : ALTADENA, PRESS RESIDENCE No. 28



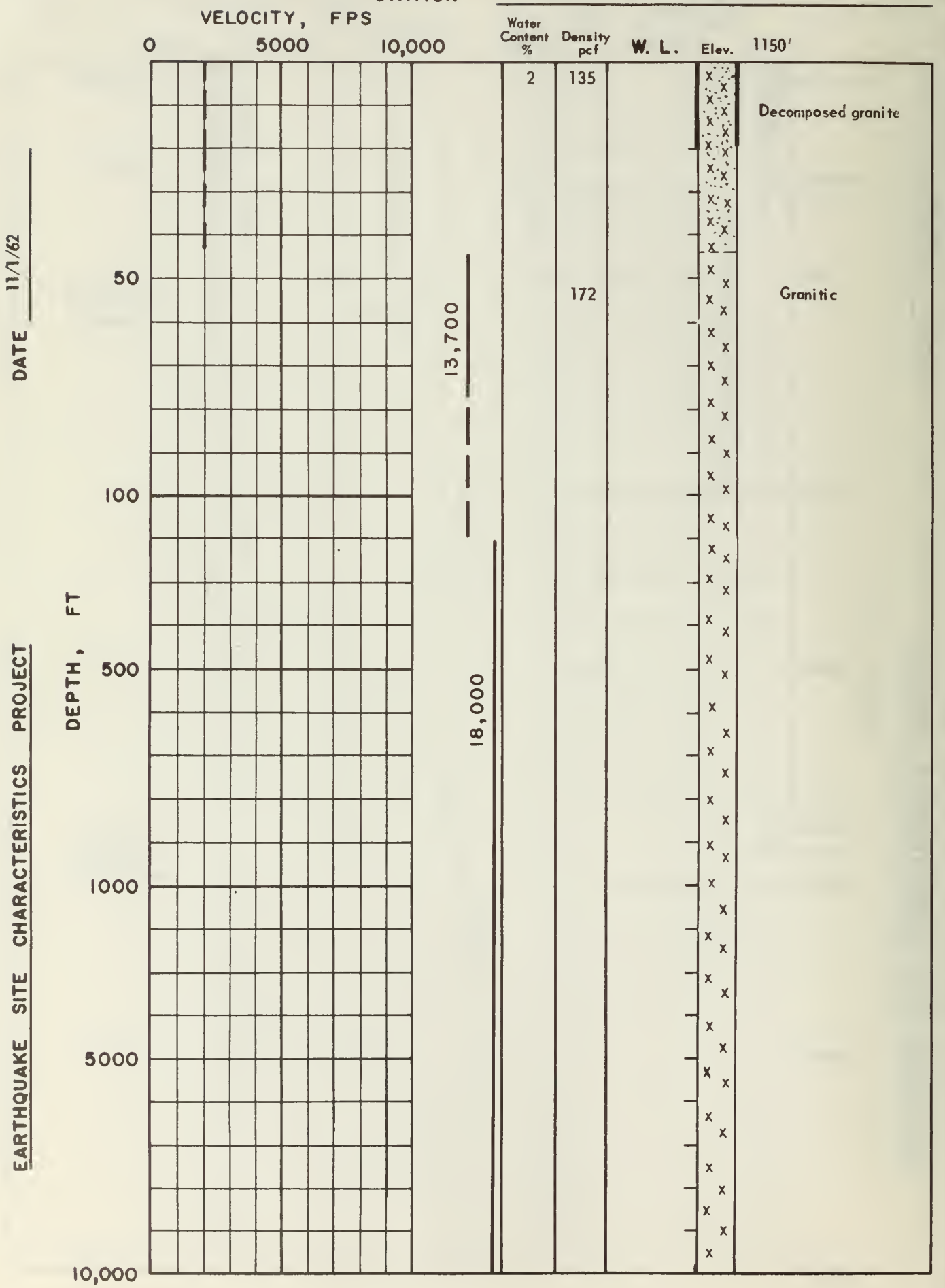
EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : ALTADENA, GILMAN RESIDENCE No. 29



STATION : PASADENA, WASHINGTON JR HIGH SCHOOL No. 30



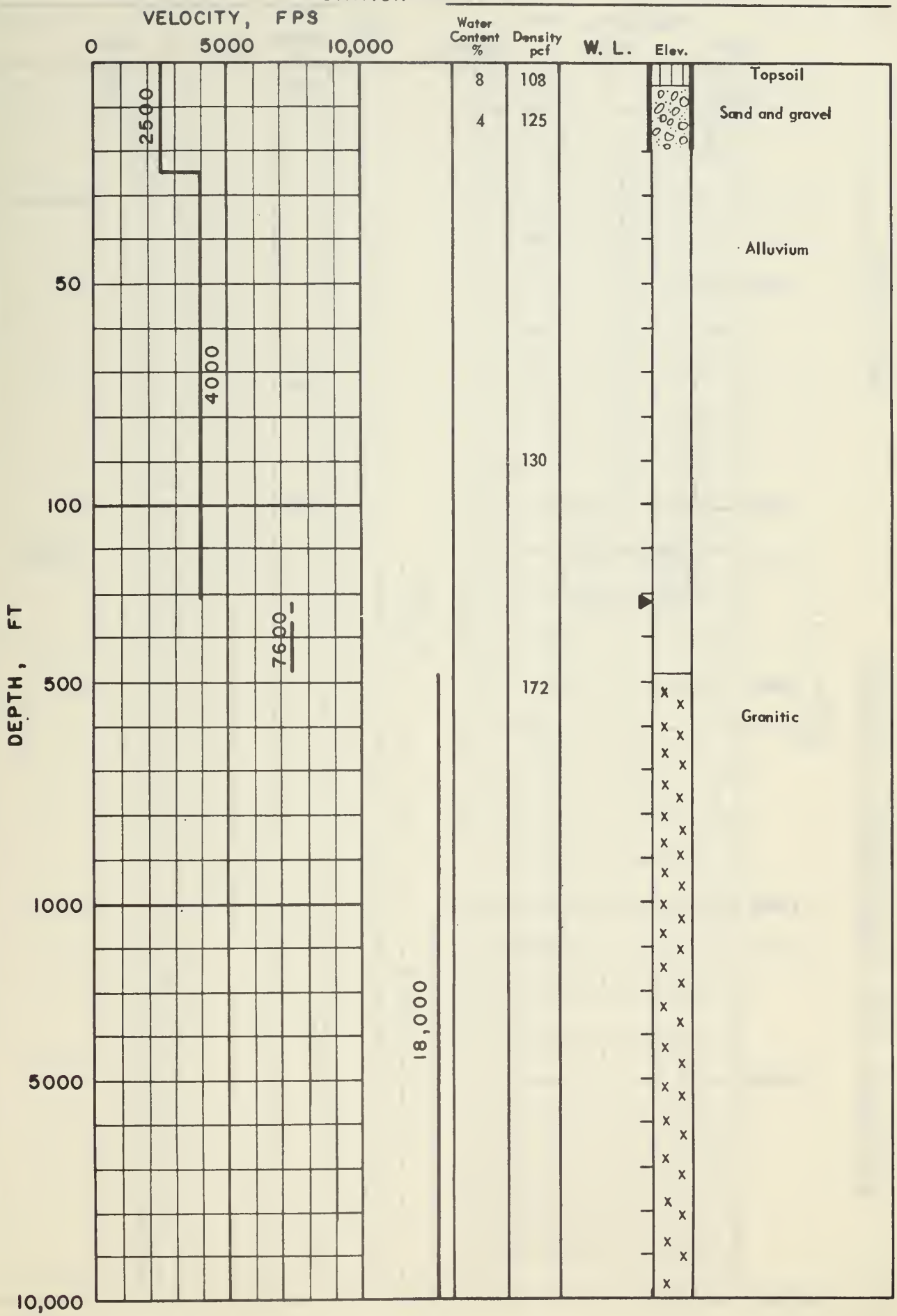
DATE 11/1/62

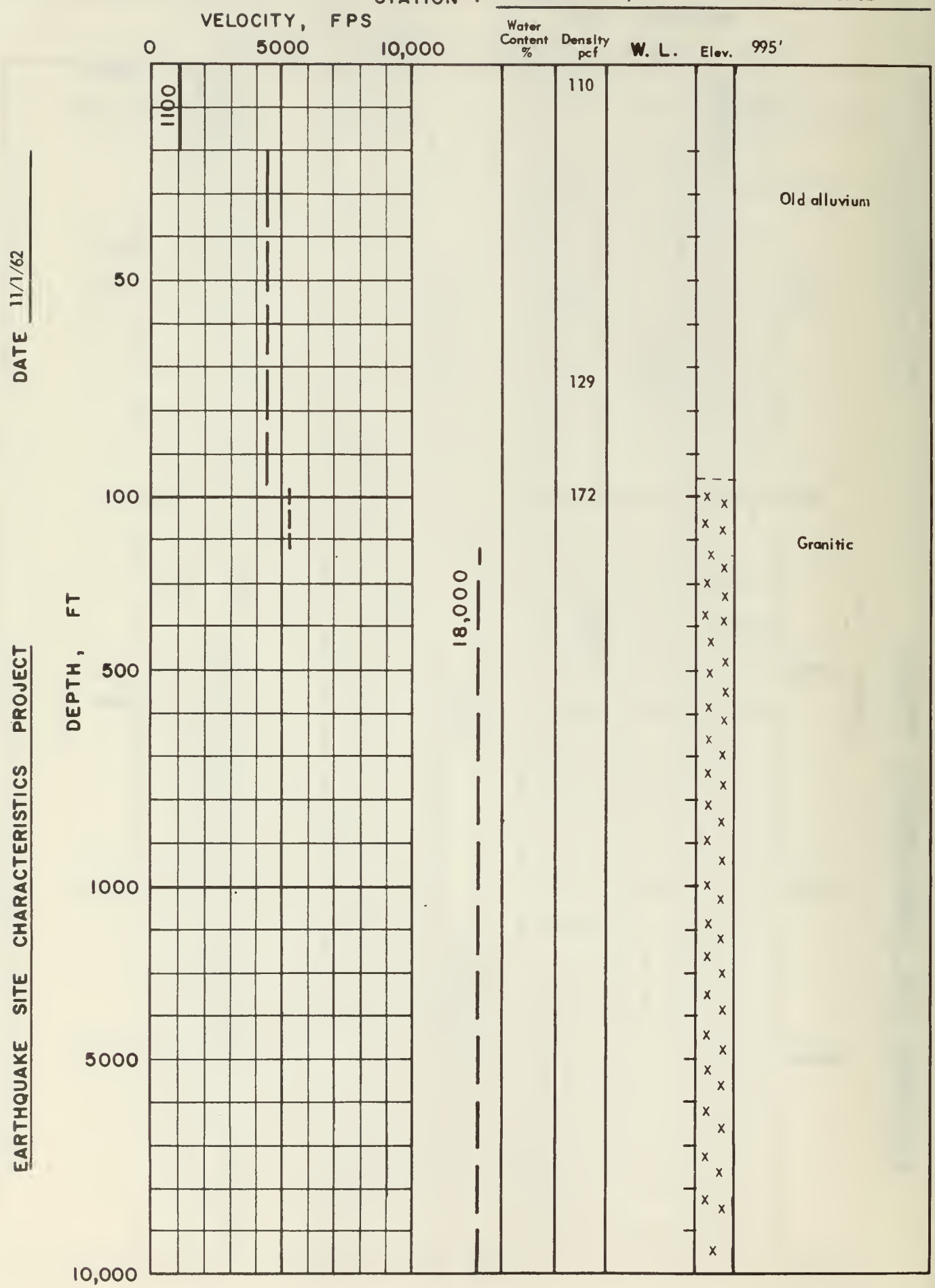
EARTHQUAKE SITE CHARACTERISTICS PROJECT

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : PASADENA, JOHN MUIR HIGH SCHOOL No. 31

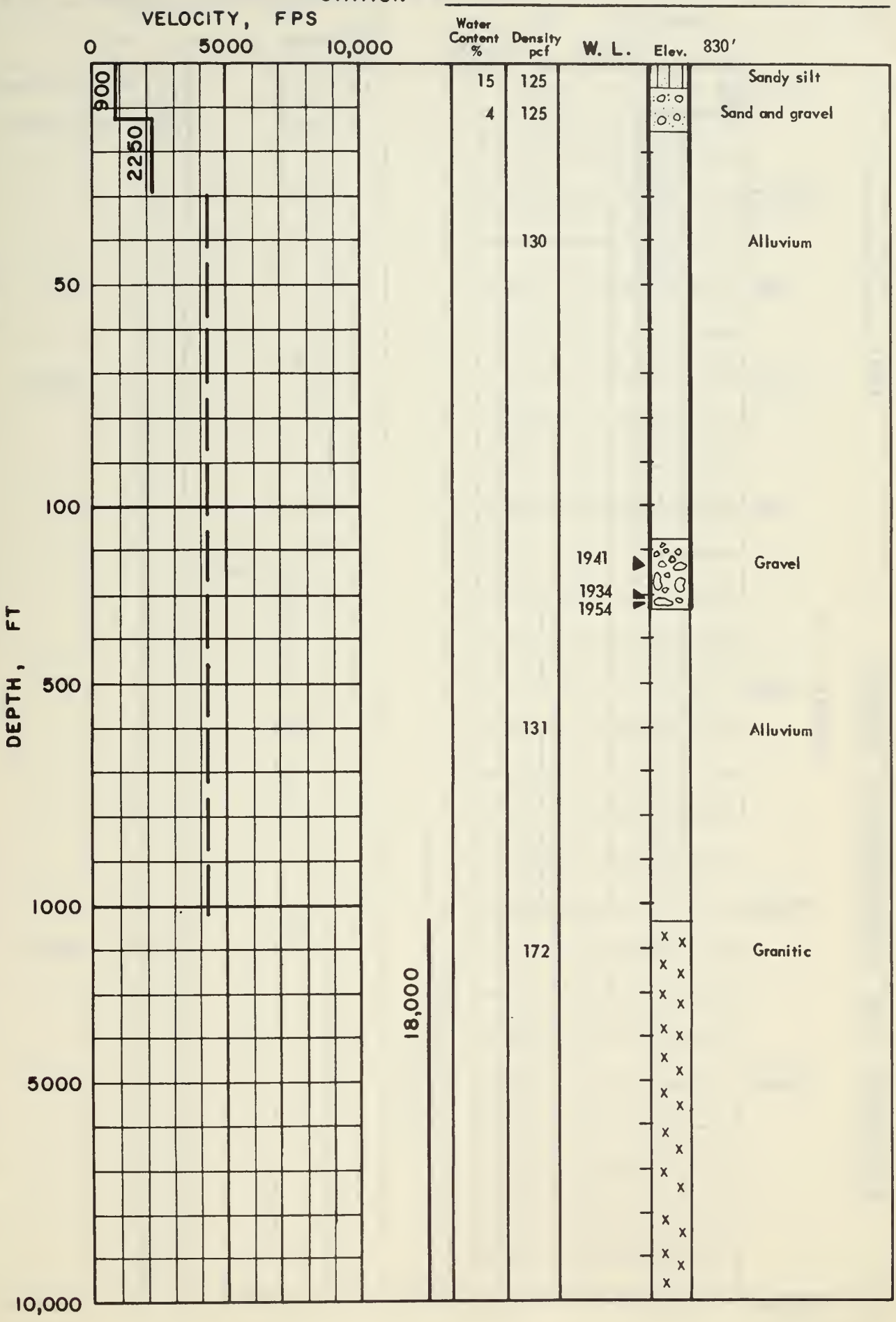



STATION : PASADENA, MOTTA RESIDENCE No. 32
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 995'
1100
18,000
110
129
172
Old alluvium
Granitic
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

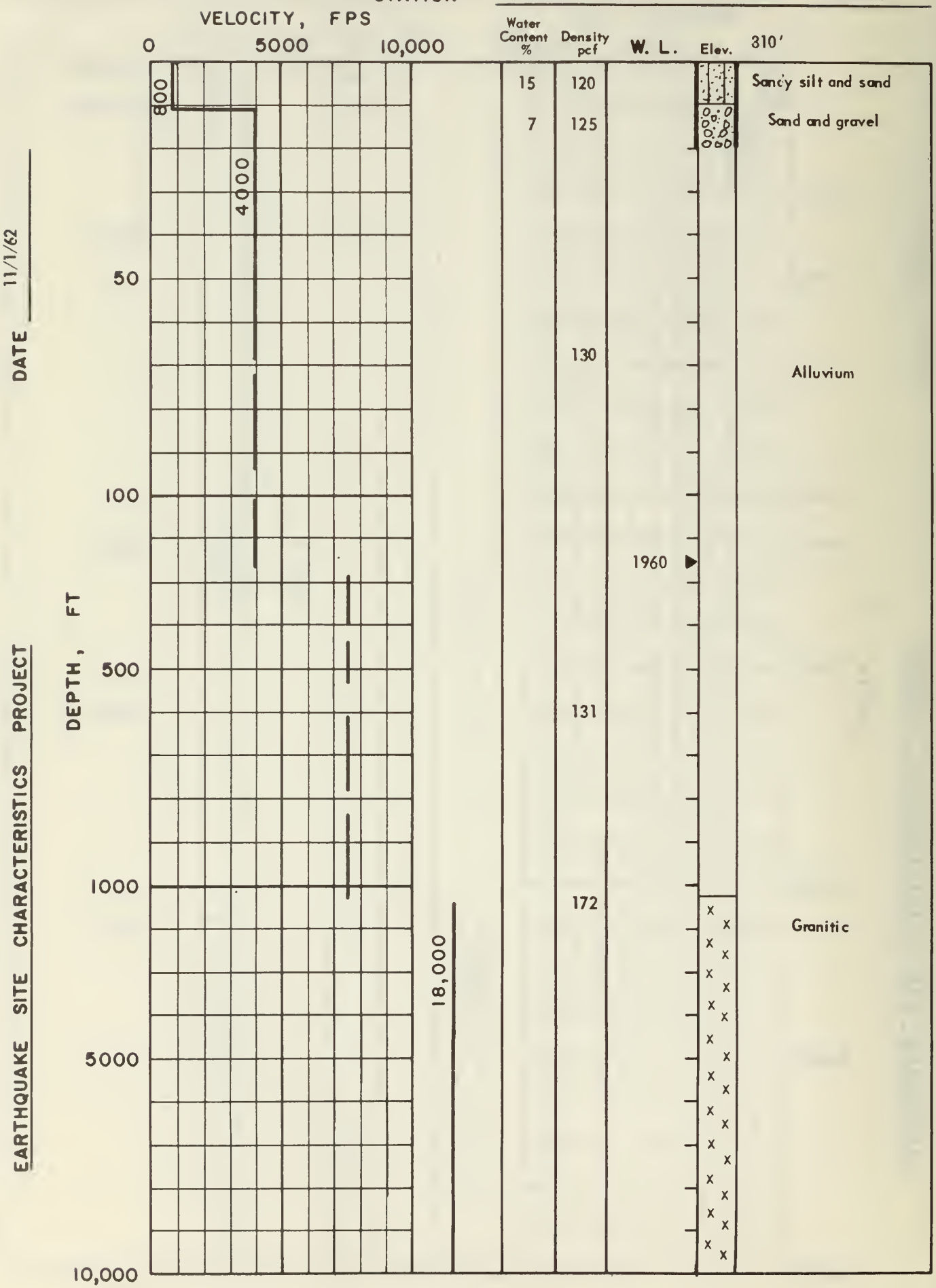
EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : PASADENA, HALE ELEM. SCHOOL No. 33



STATION : PASADENA, NORDQUIST RESIDENCE No. 34



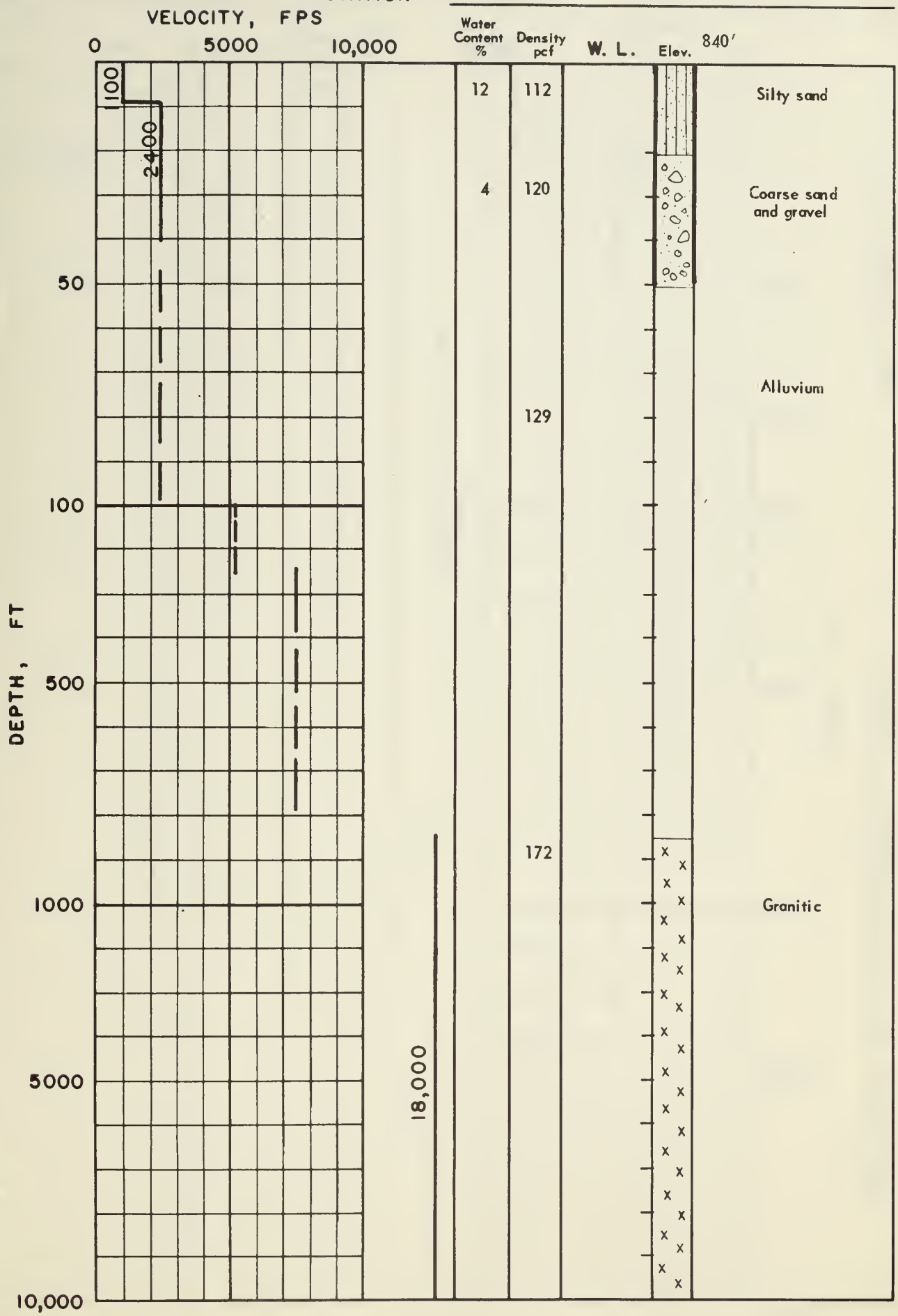
EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

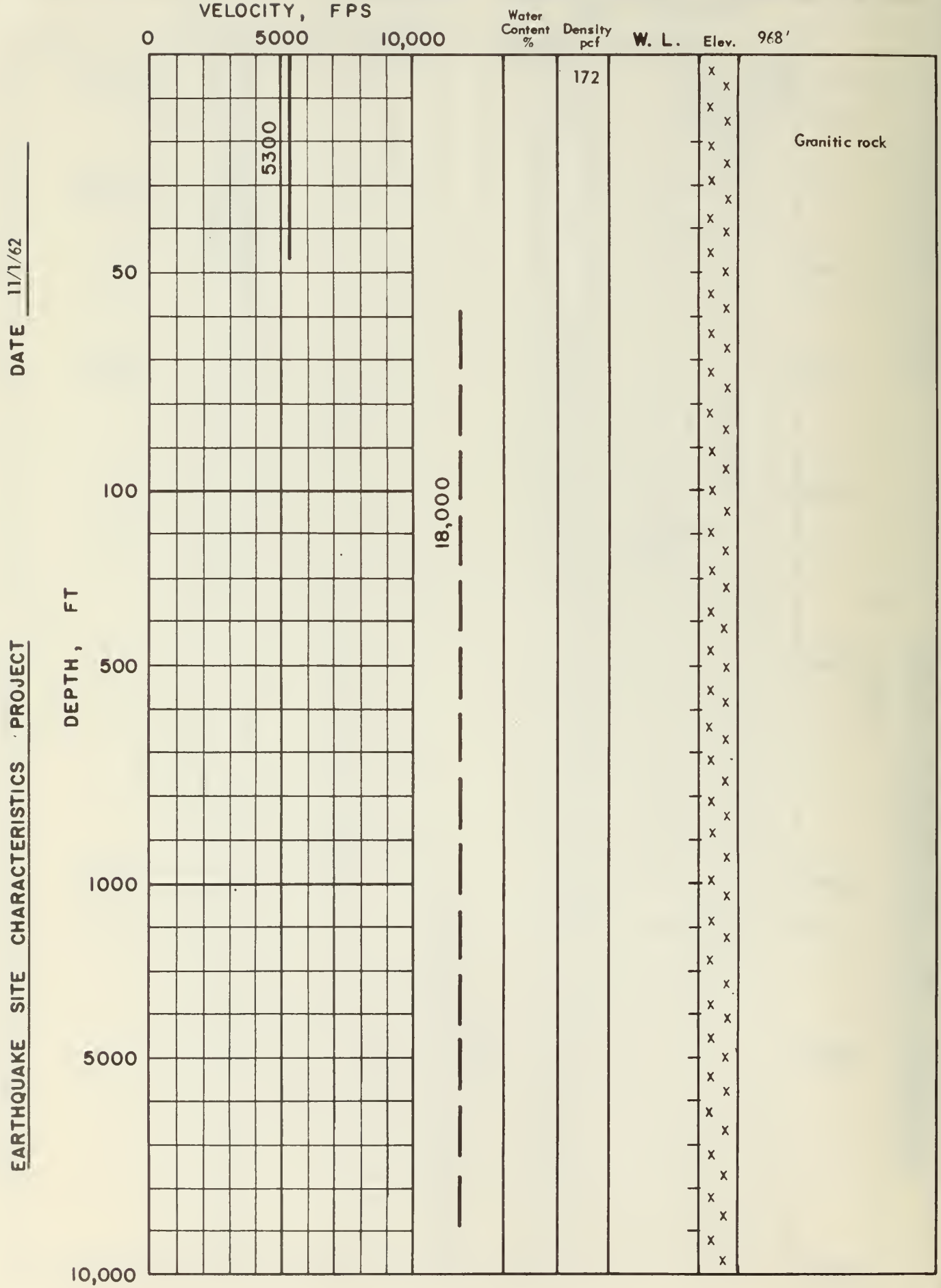
EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : PASADENA, STAR-NEWS BLDG No 35



STATION : PASADENA, C.I.T SEISMOLOGICAL LAB No. 36



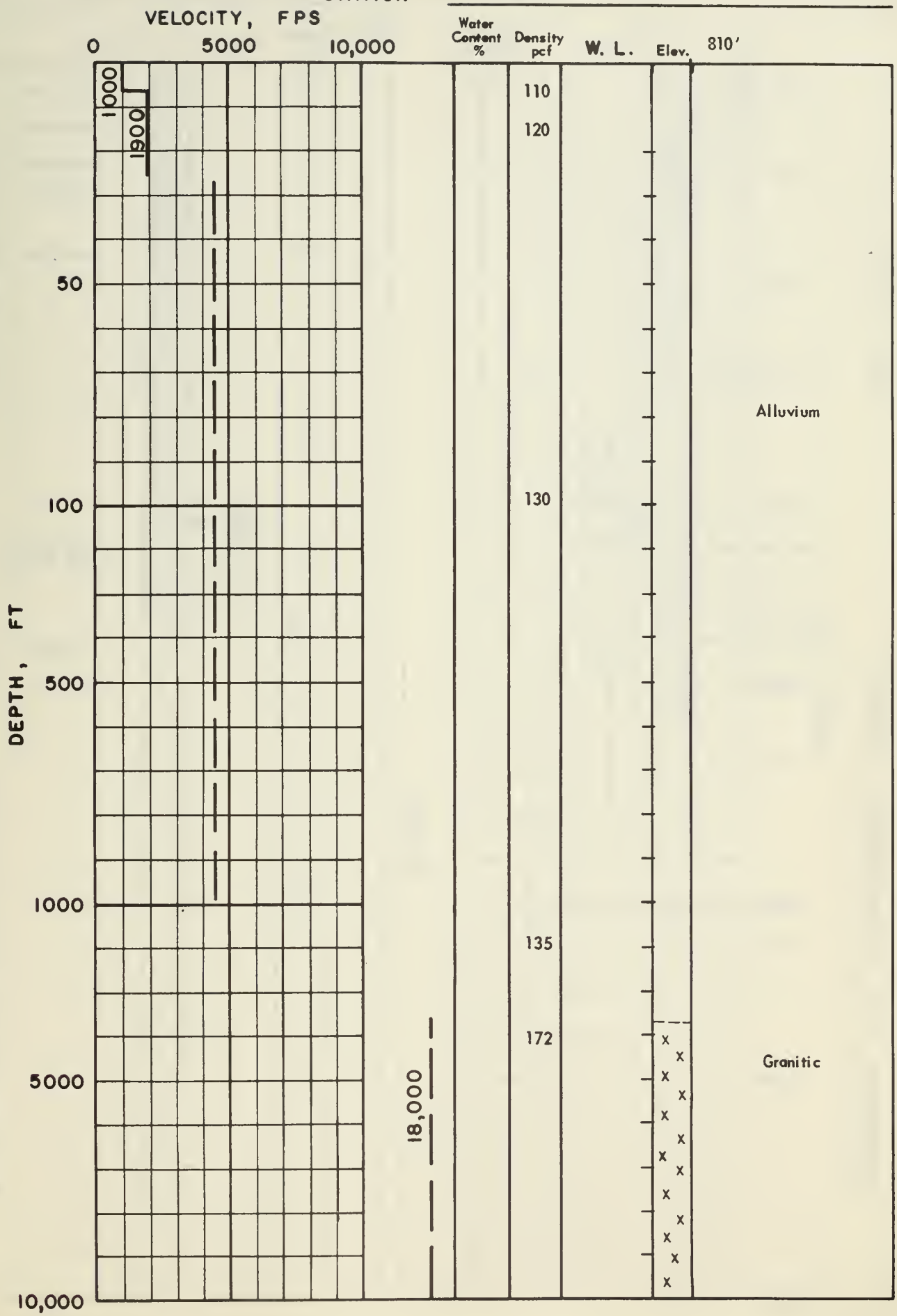
DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

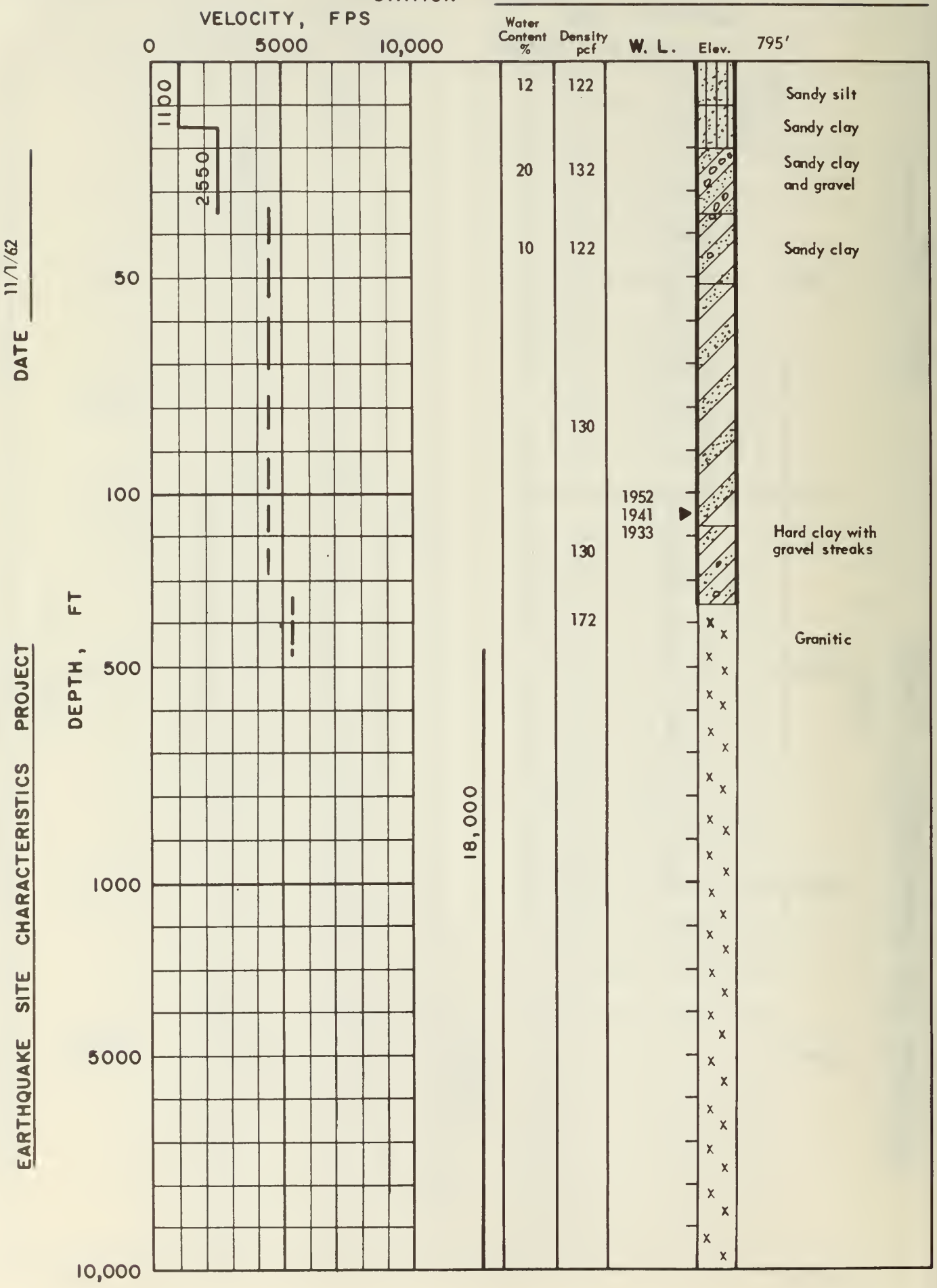
STATION : PASADENA, SAN RAFAEL ELEM. SCHOOL No 37



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

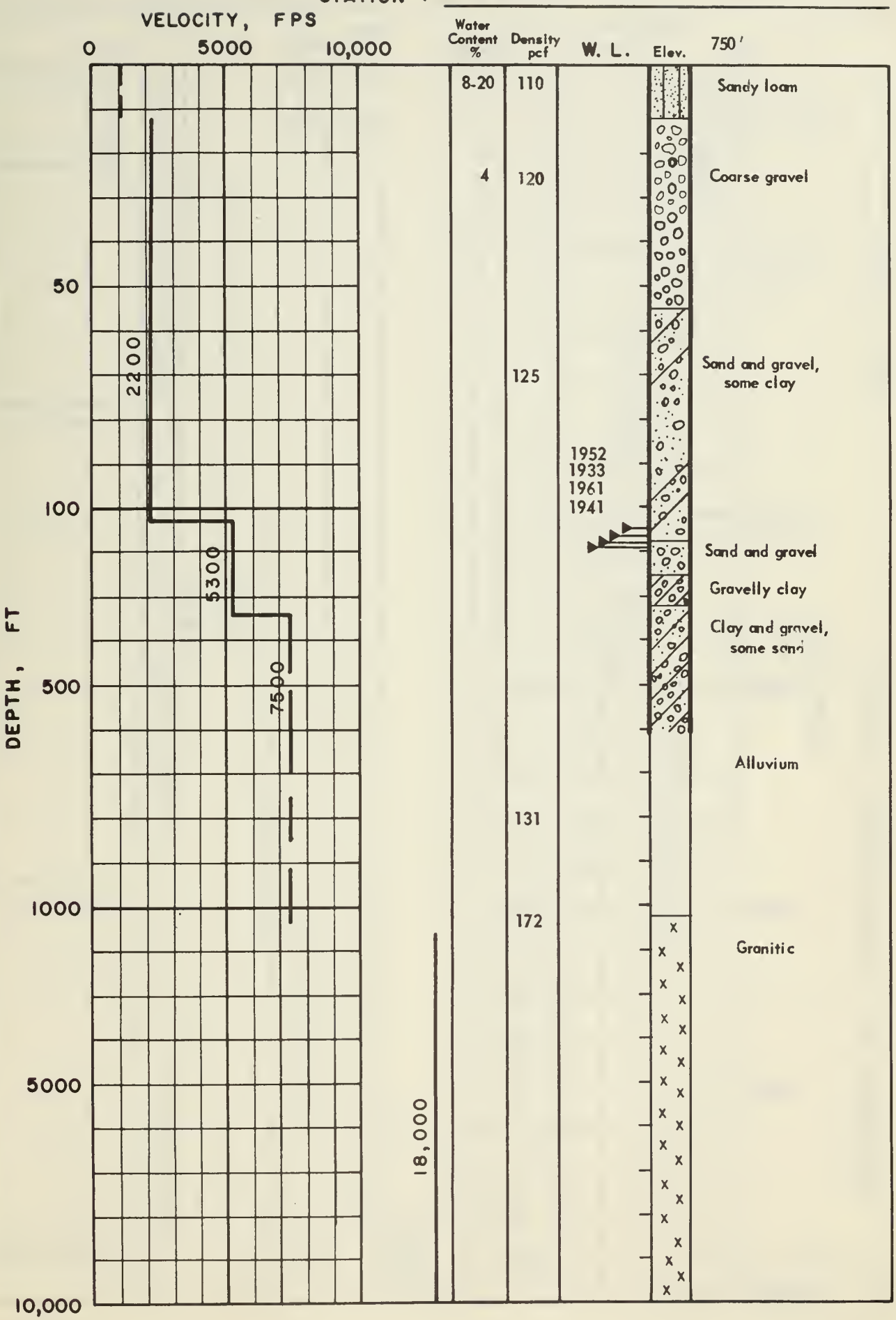
STATION : PASADENA, GARFIELD ELEM. SCHOOL No. 38



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

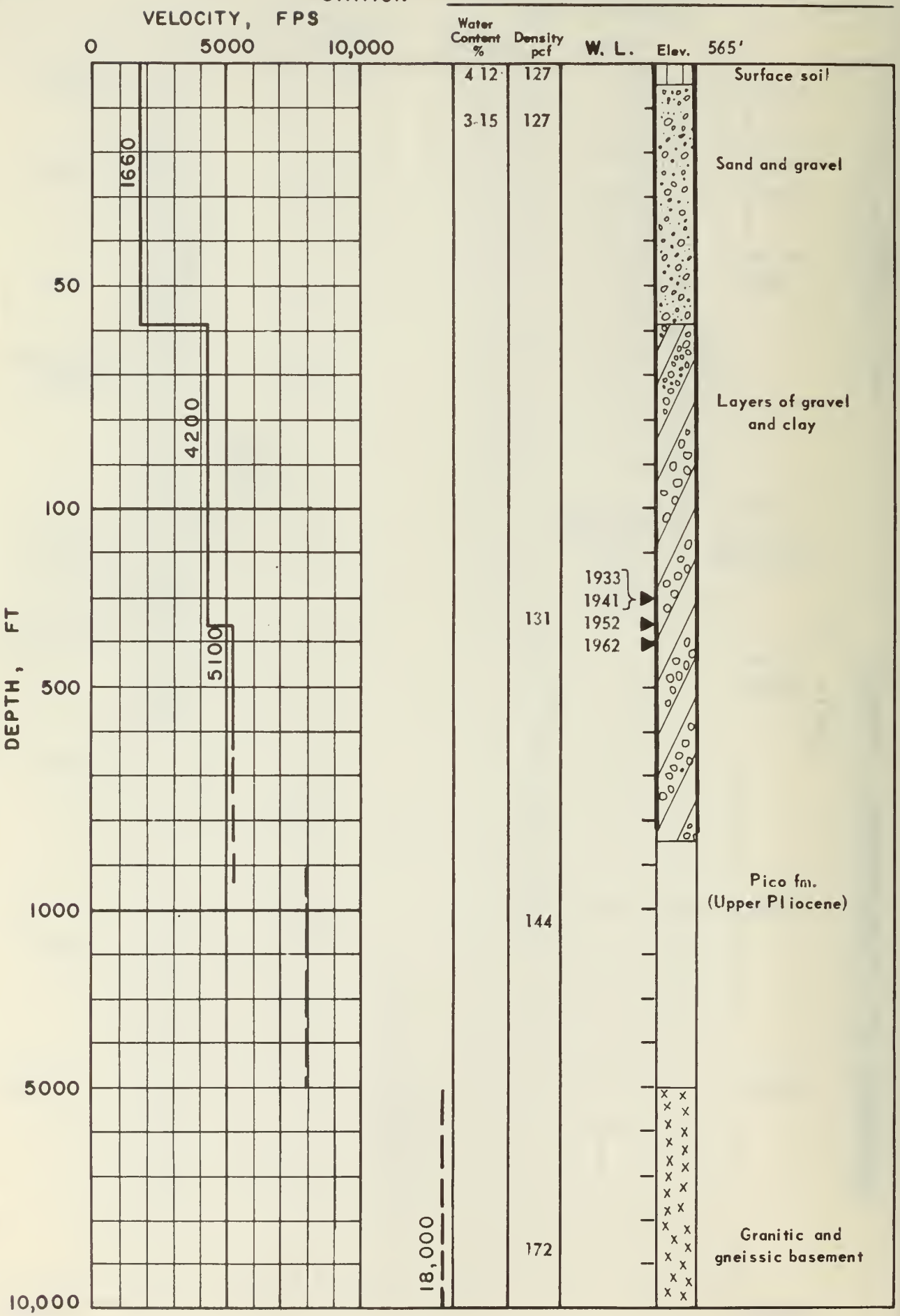
STATION : PASADENA, CAL. TECH. No. 39



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

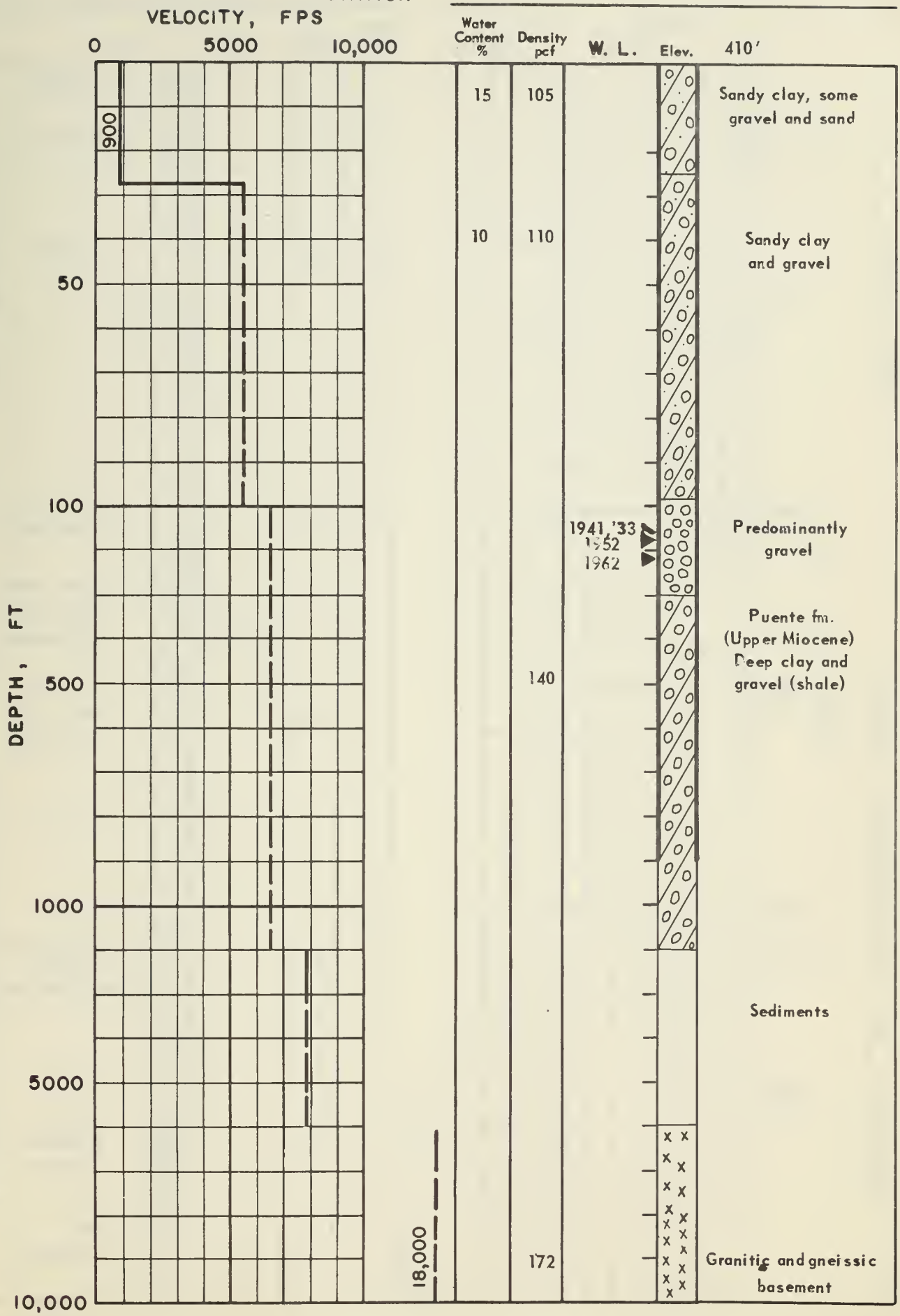
STATION : SAN MARINO CITY HALL No. 40



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

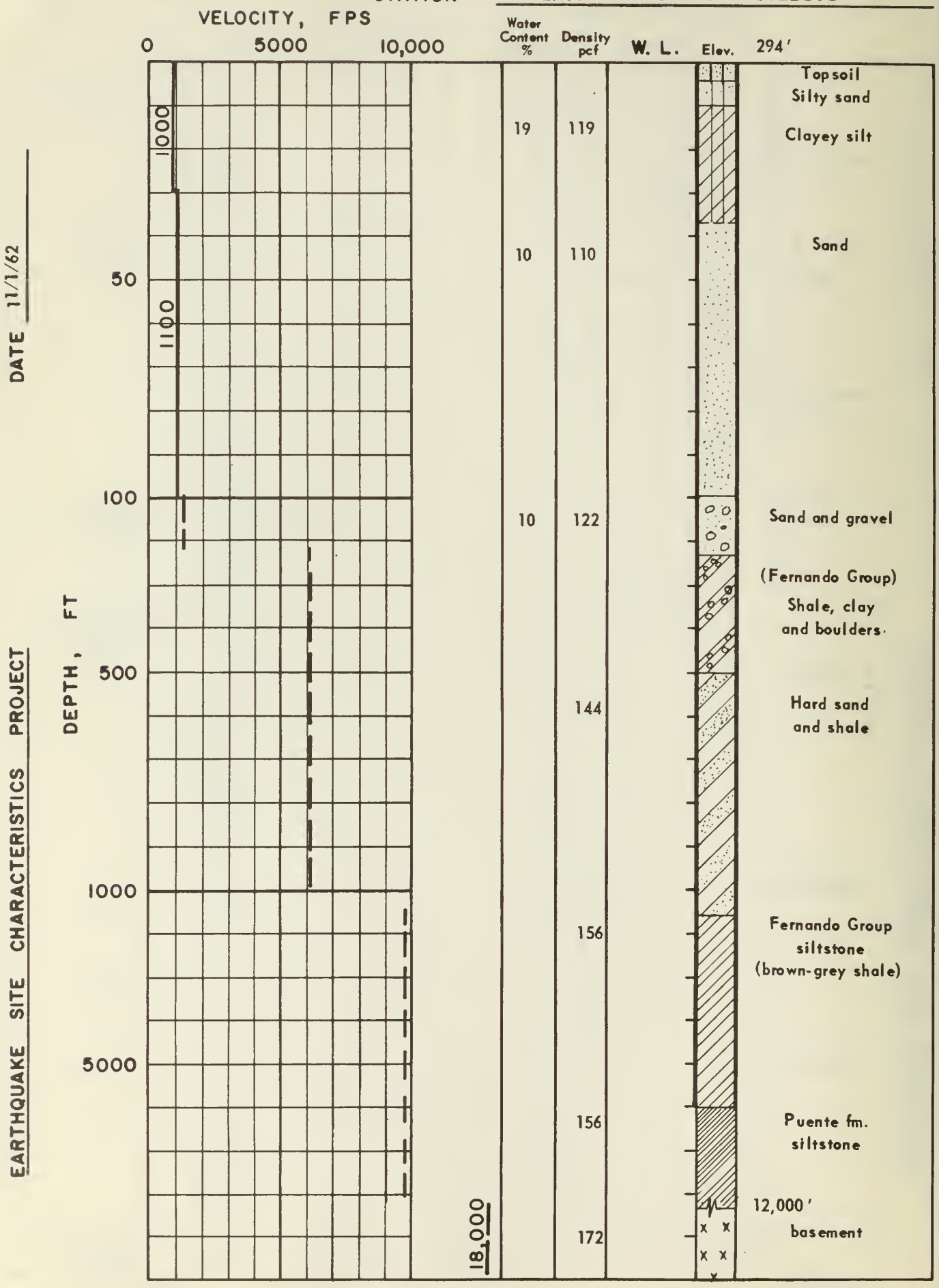
STATION : ALHAMBRA, TAYLOR RESIDENCE No. 41



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

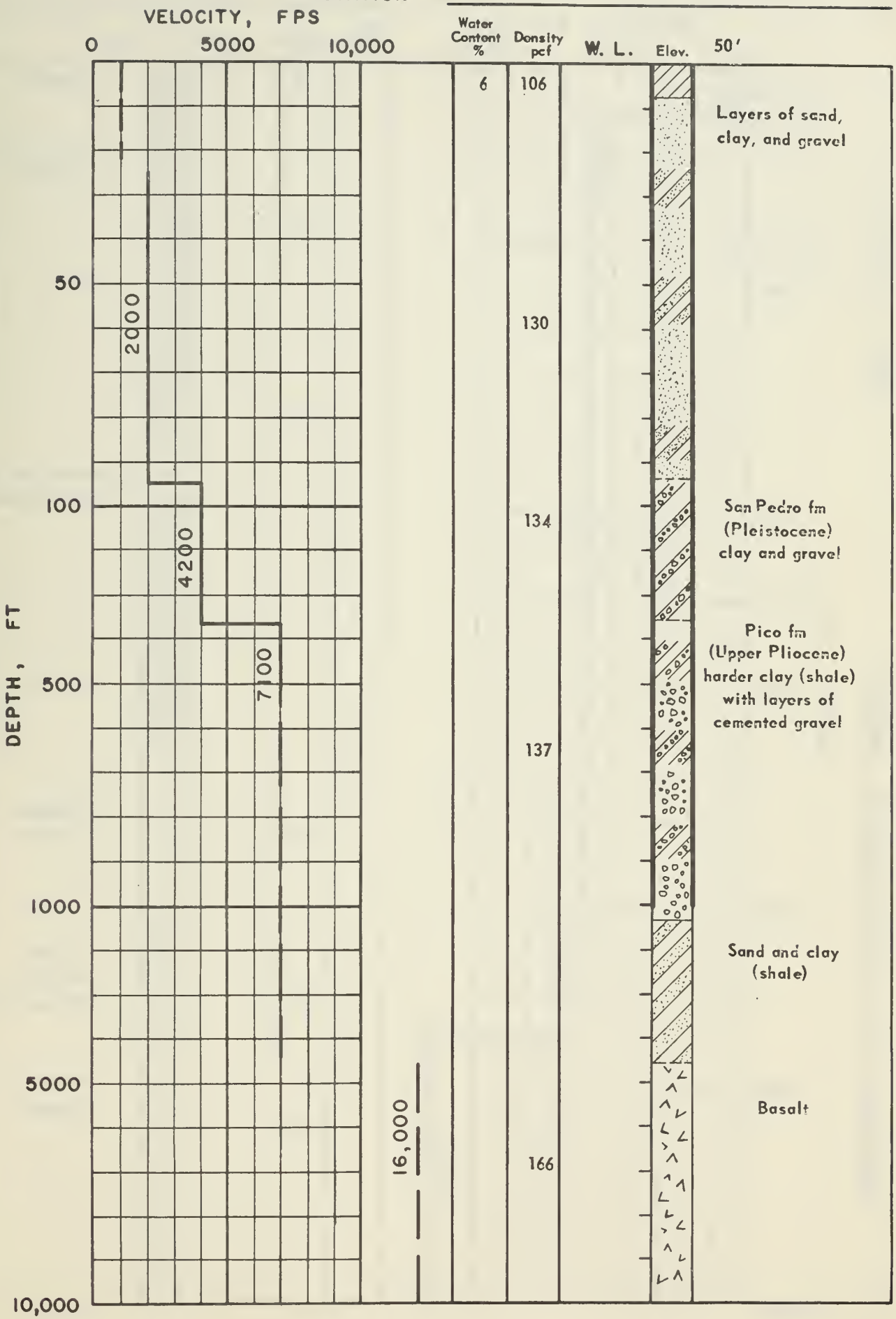
STATION : EAST LOS ANGELES JR. COLLEGE No. 42

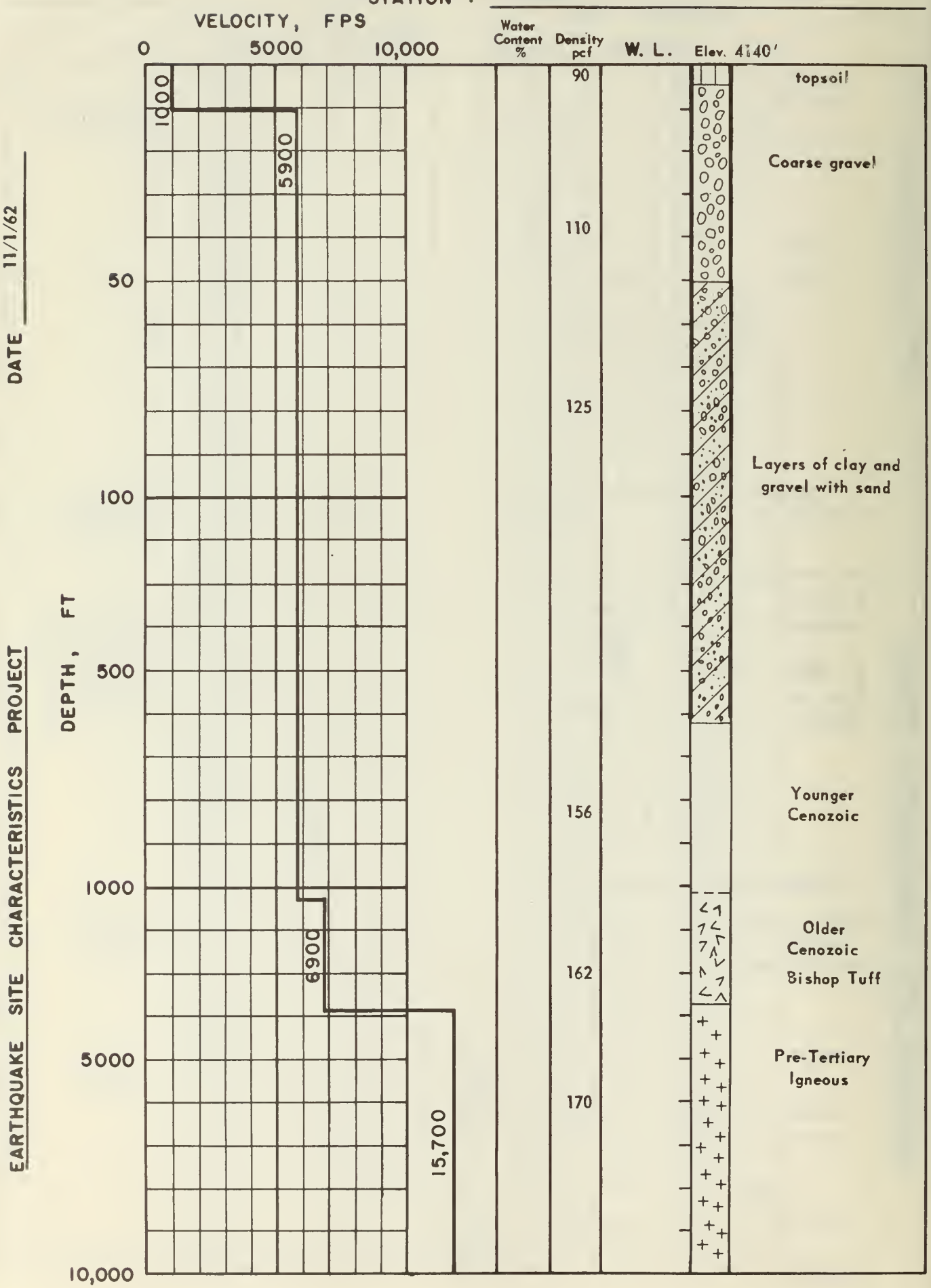


EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : SANTA ANA No. 43

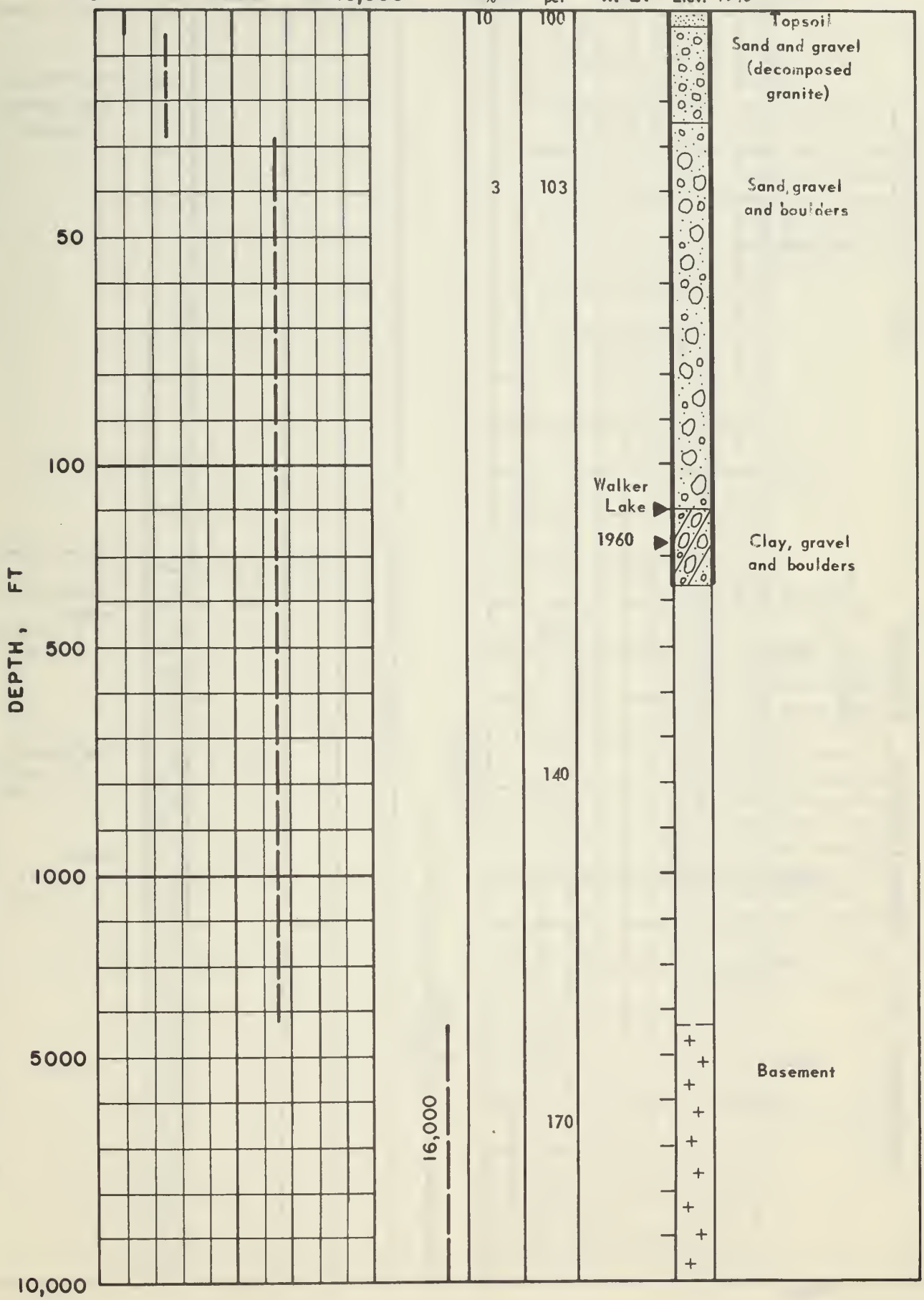


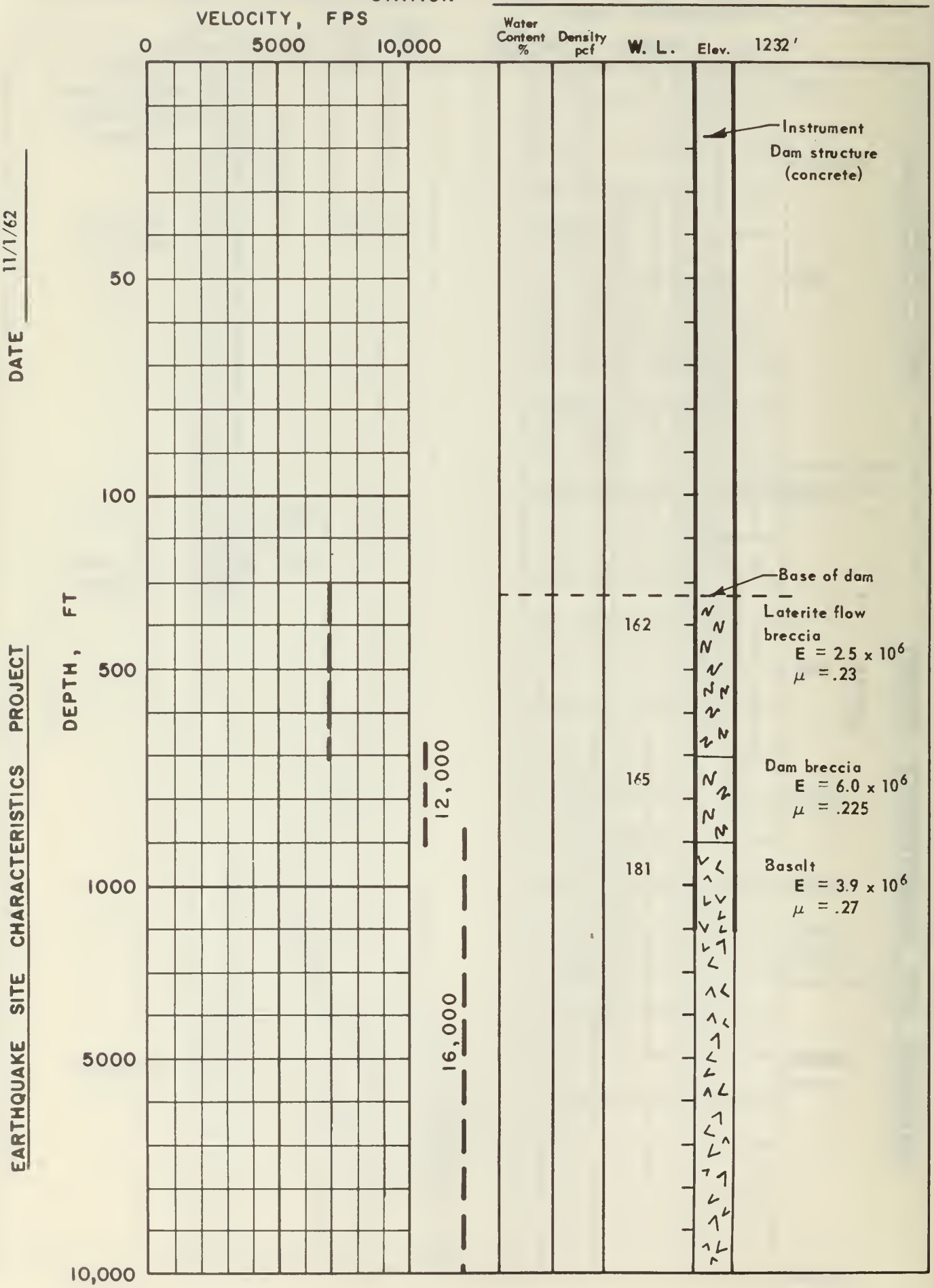

STATION : BISHOP No. 44
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 4140'
1000
5900
6900
15,700
90
110
125
156
162
170
50
100
500
1000
5000
10,000
DEPTH, FT
topsoil
Coarse gravel
Layers of clay and gravel with sand
Younger Cenozoic
Older Cenozoic
Bishop Tuff
Pre-Tertiary Igneous
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

STATION : HAWTHORNE, NEVADA No. 45

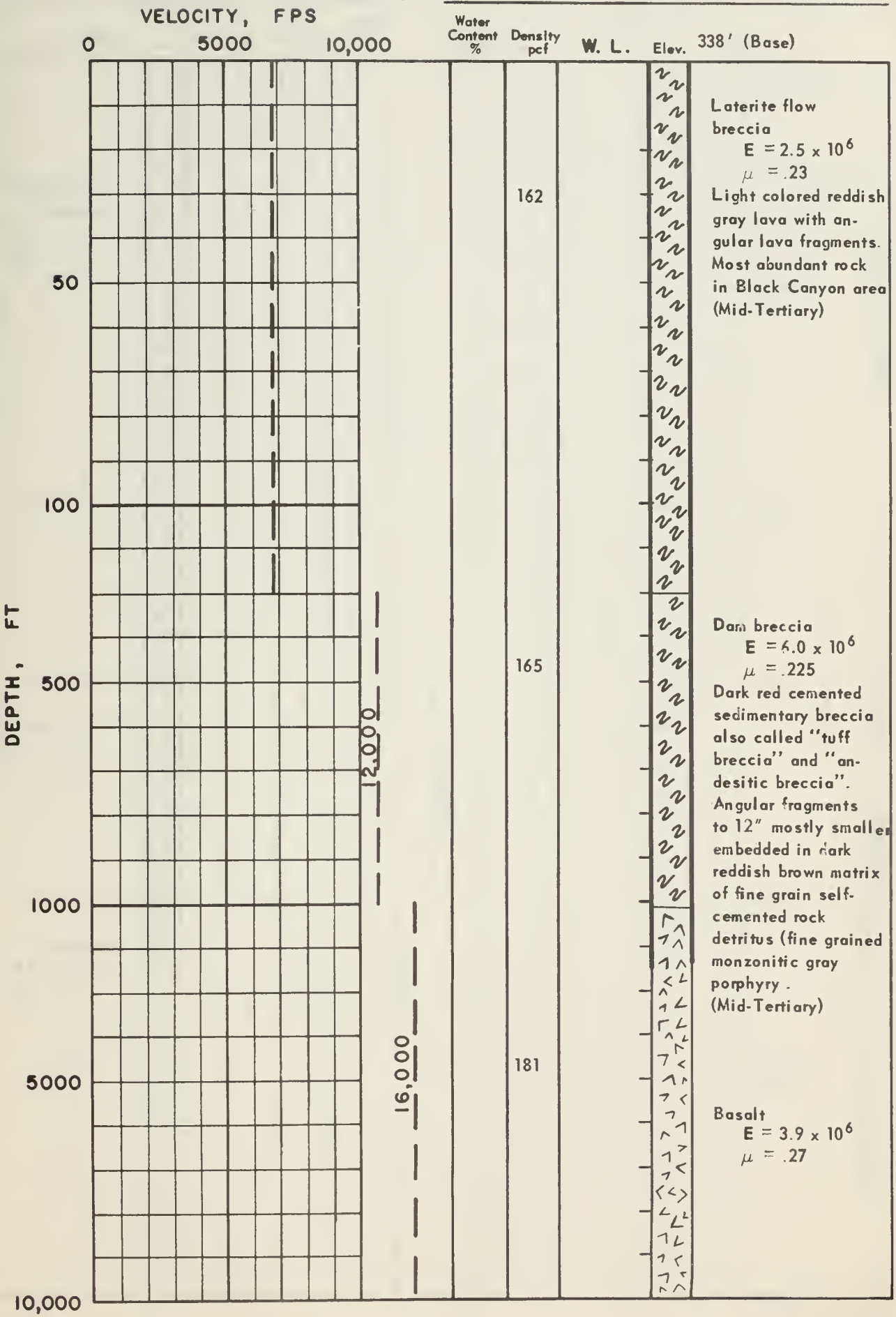
DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT




STATION : HOOVER DAM, GALLERY 1215 No. 46
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 1232'
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT
DEPTH, FT
50
100
500
1000
5000
10,000
12,000
16,000
Instrument
Dam structure (concrete)
Base of dam
162
Laterite flow breccia
E = 2.5 x 10^6
μ = .23
165
Dam breccia
E = 6.0 x 10^6
μ = .225
181
Basalt
E = 3.9 x 10^6
μ = .27

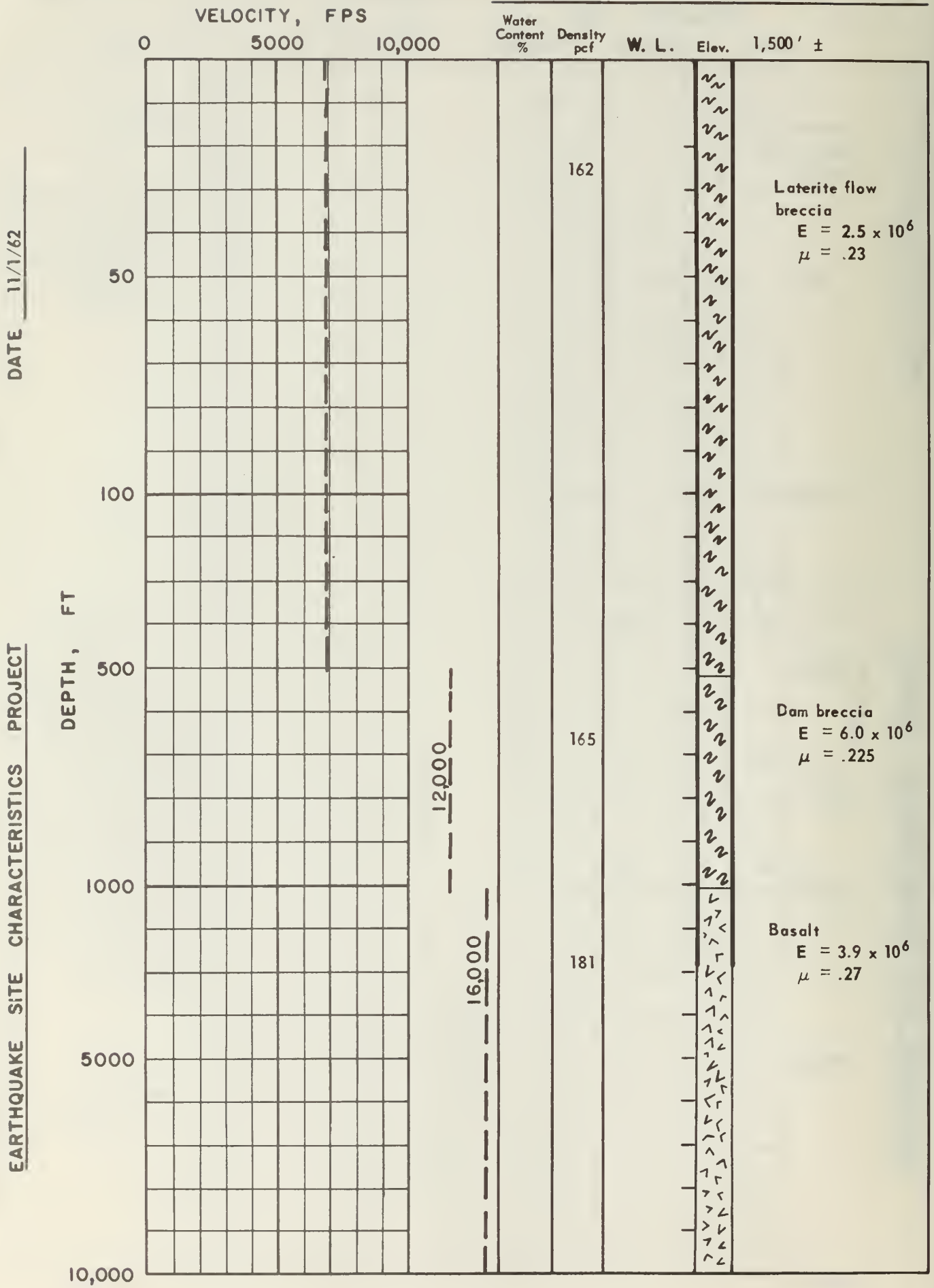
STATION : HOOVER DAM, (NEVADA) INTAKE TOWER No. 47



DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

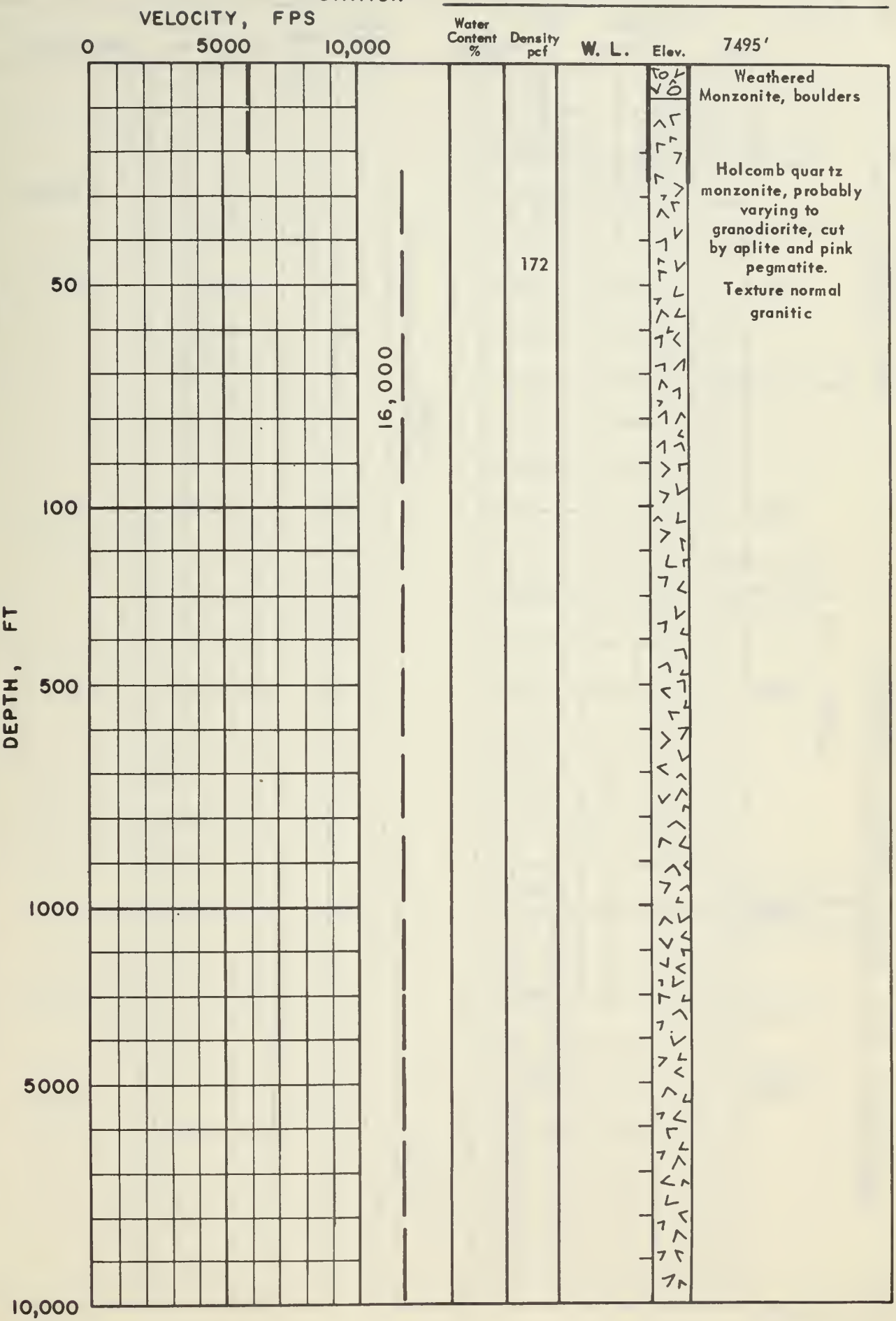
STATION : HOOVER DAM, OILHOUSE NEVADA No. 48



DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

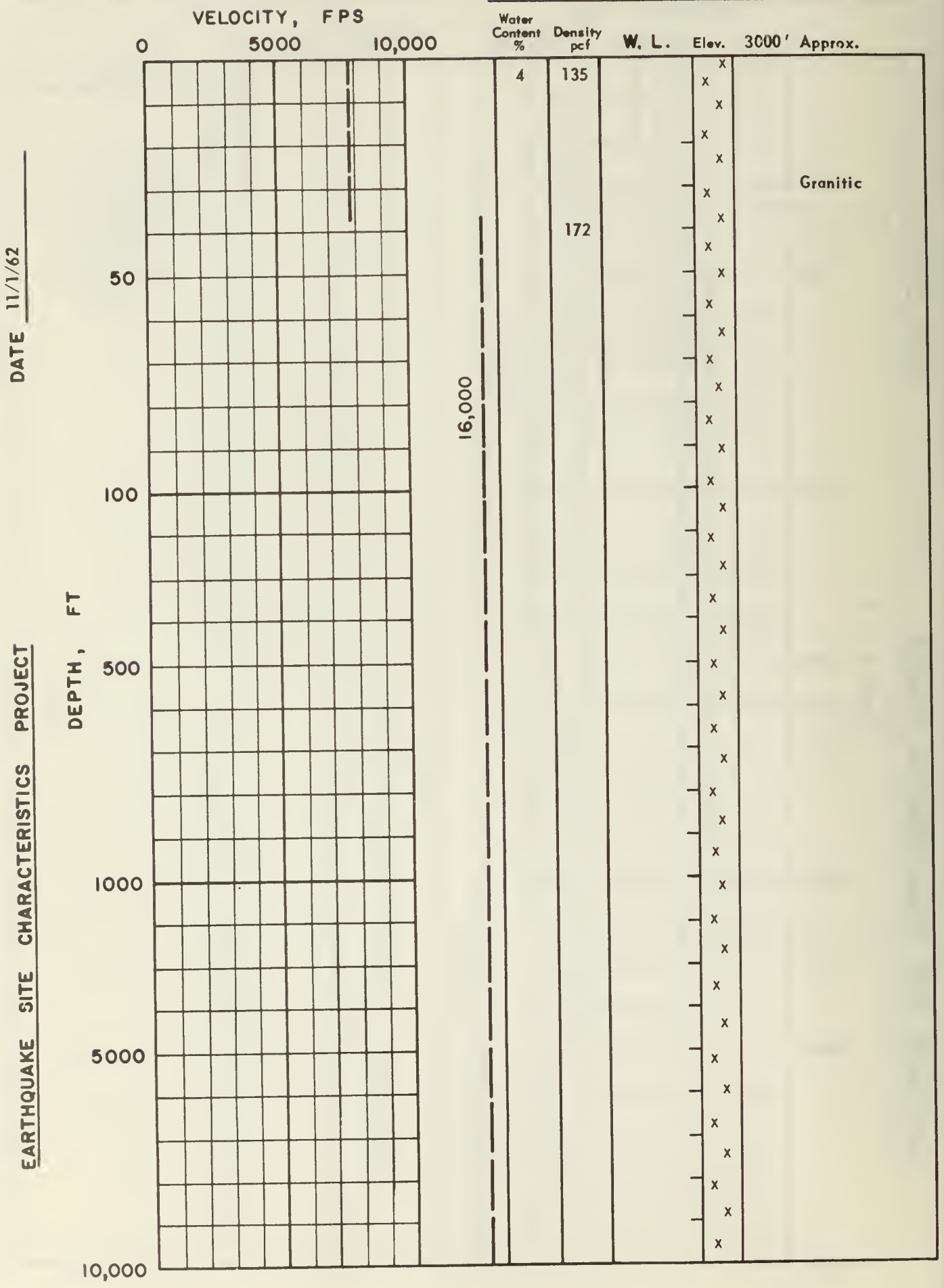
STATION : TABLE MT. - SMITHSONIAN OBS. No. 49



DATE 11/1/62

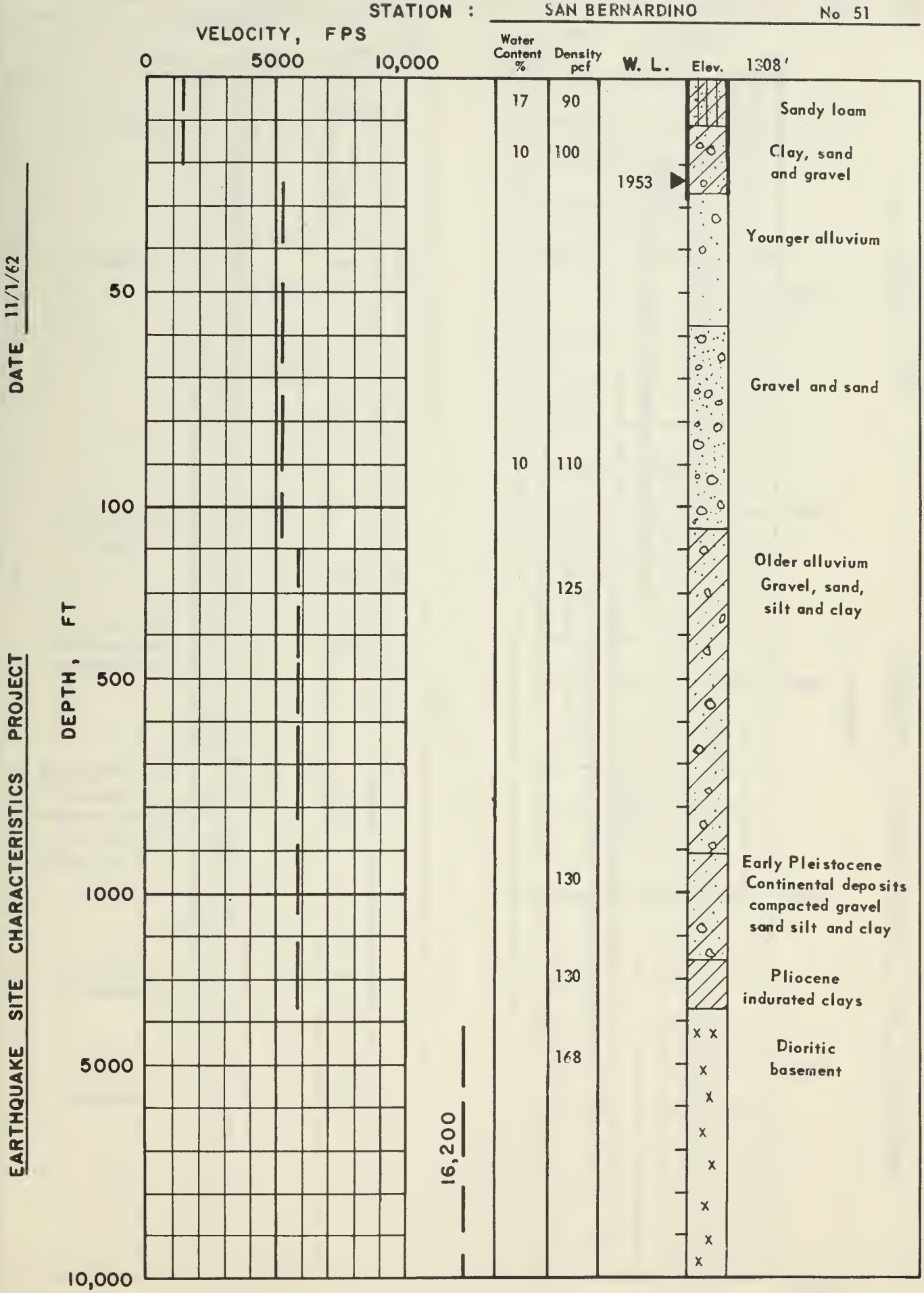
EARTHQUAKE SITE CHARACTERISTICS PROJECT

STATION : ARROWHEAD SPRINGS No. 50



DATE 11/1/62

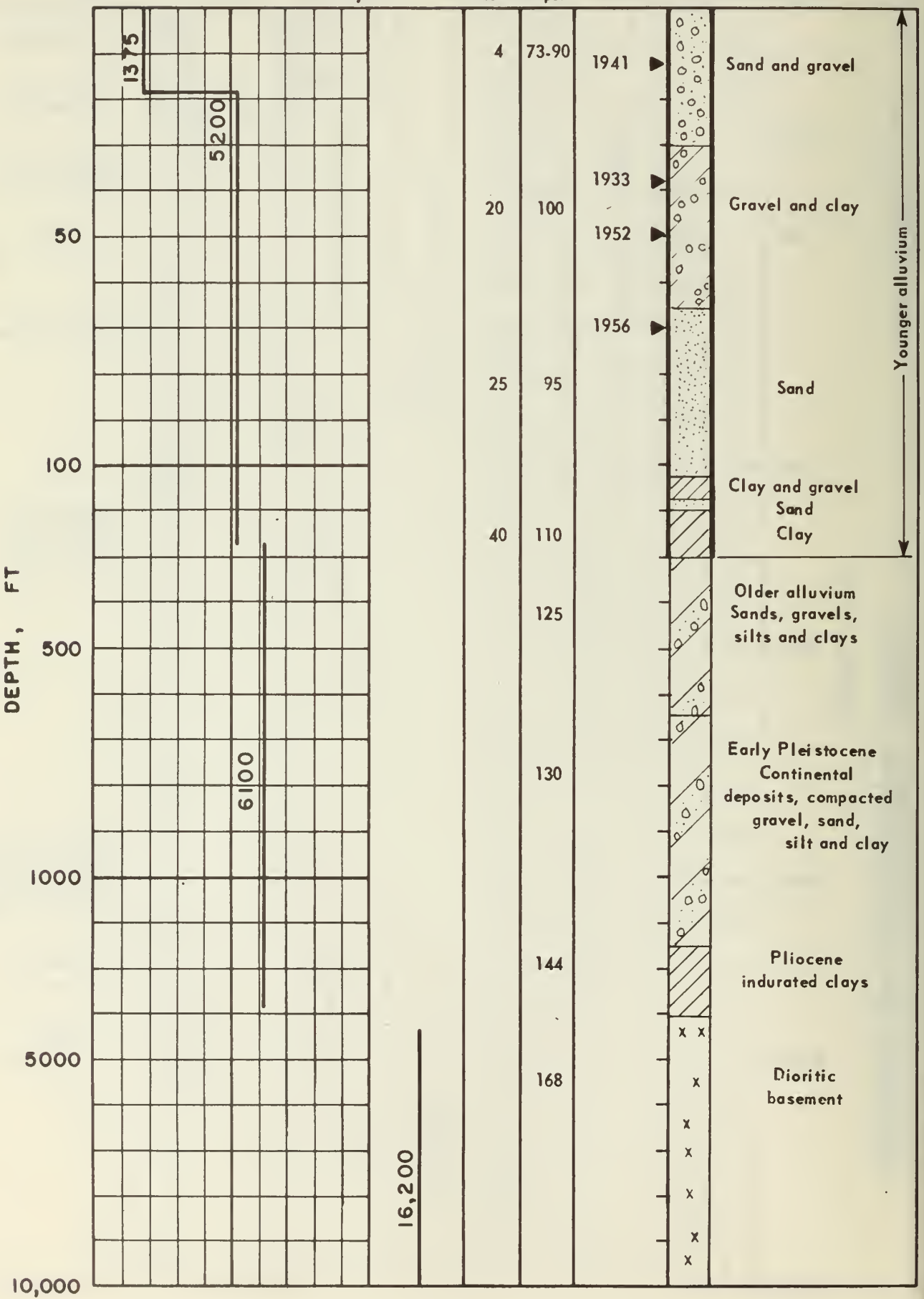
EARTHQUAKE SITE CHARACTERISTICS PROJECT


STATION : SAN BERNARDINO No. 51
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 1308'
17
90
10
100
1953
10
110
125
130
130
168
16,200
Sandy loam
Clay, sand and gravel
Younger alluvium
Gravel and sand
Older alluvium Gravel, sand, silt and clay
Early Pleistocene Continental deposits compacted gravel sand silt and clay
Pliocene indurated clays
Dioritic basement
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

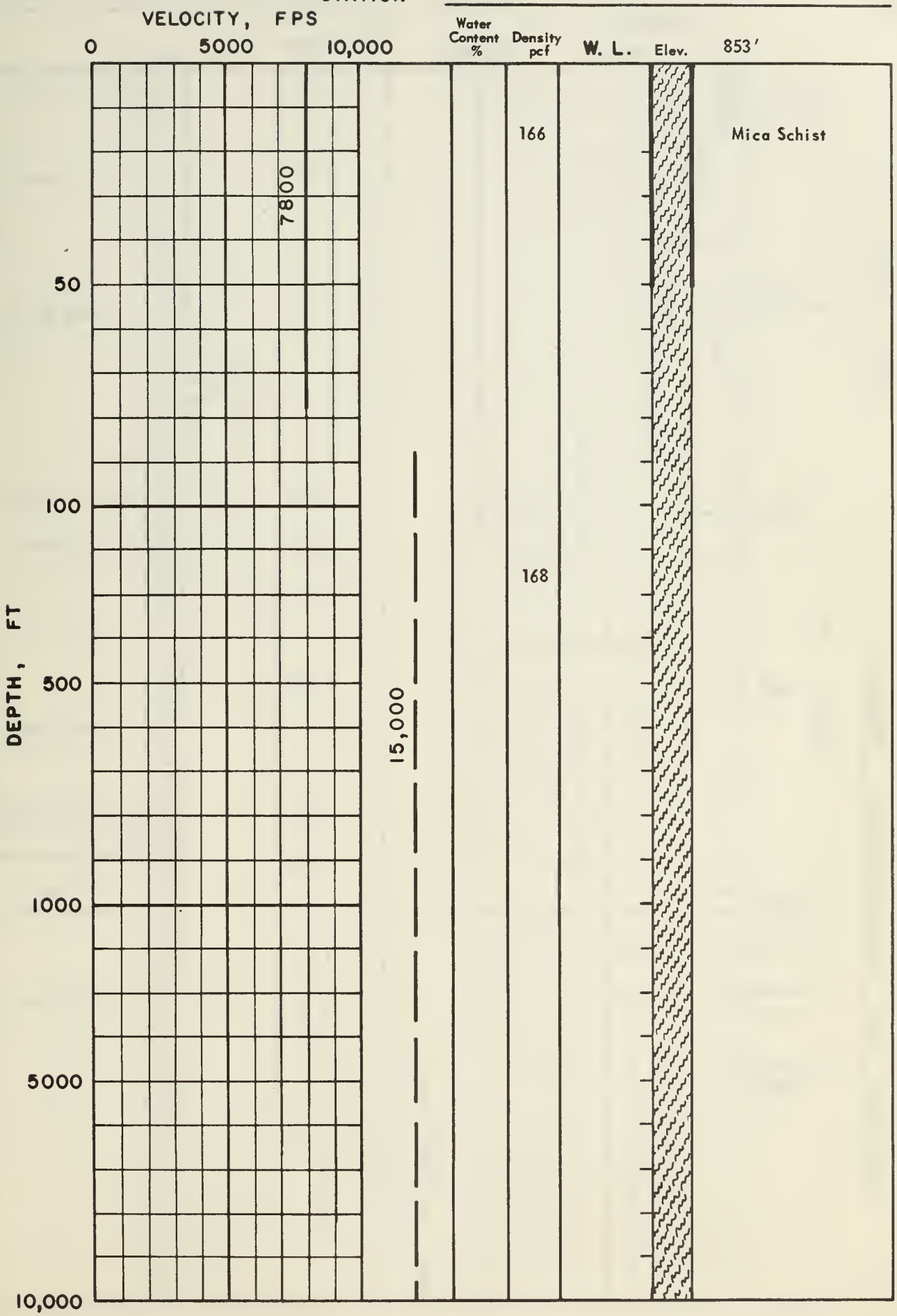
STATION : COLTON, EDISON SUB. No. 52

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

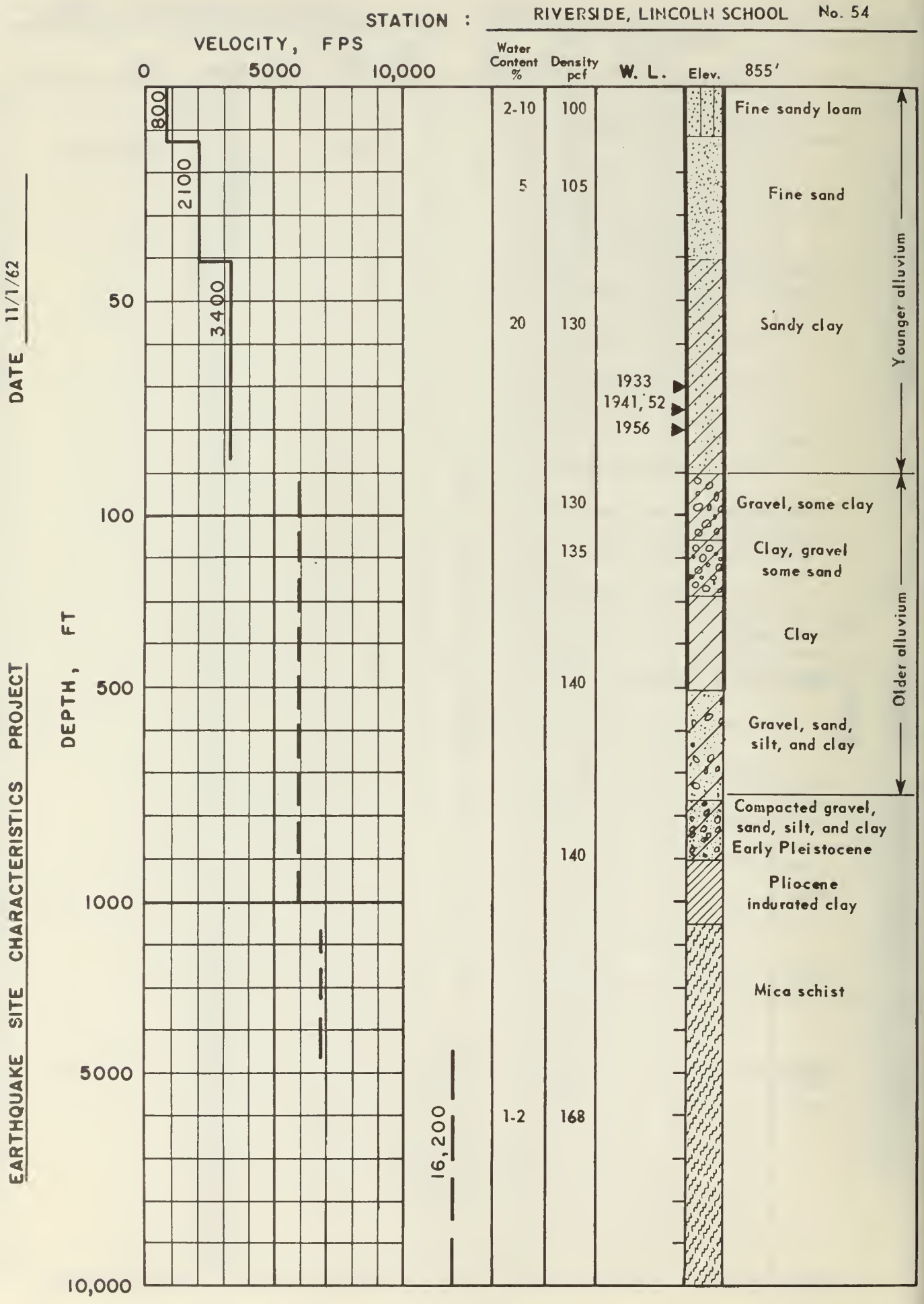


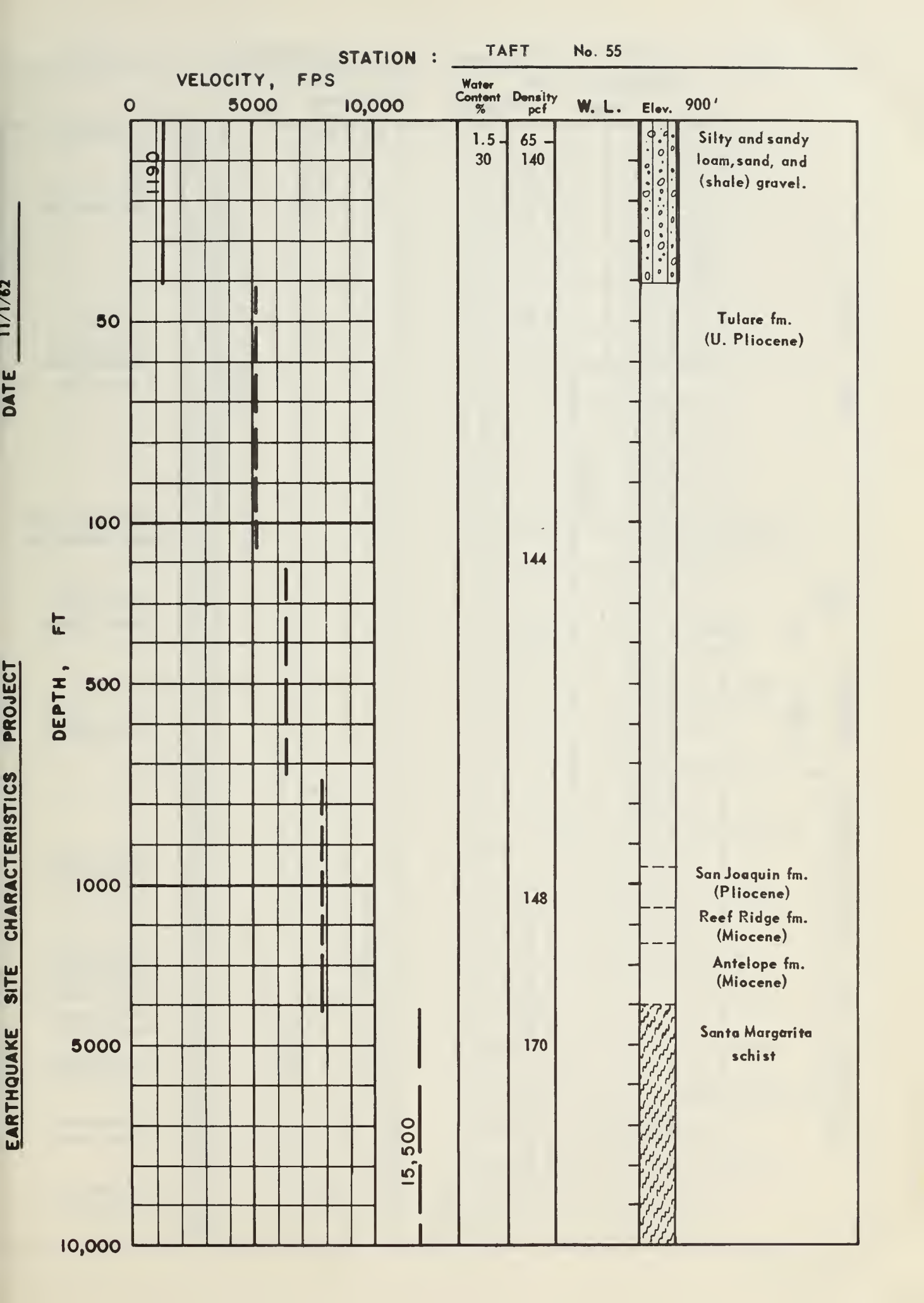
STATION : RIVERSIDE, SEISMOGRAPH STATION No.53

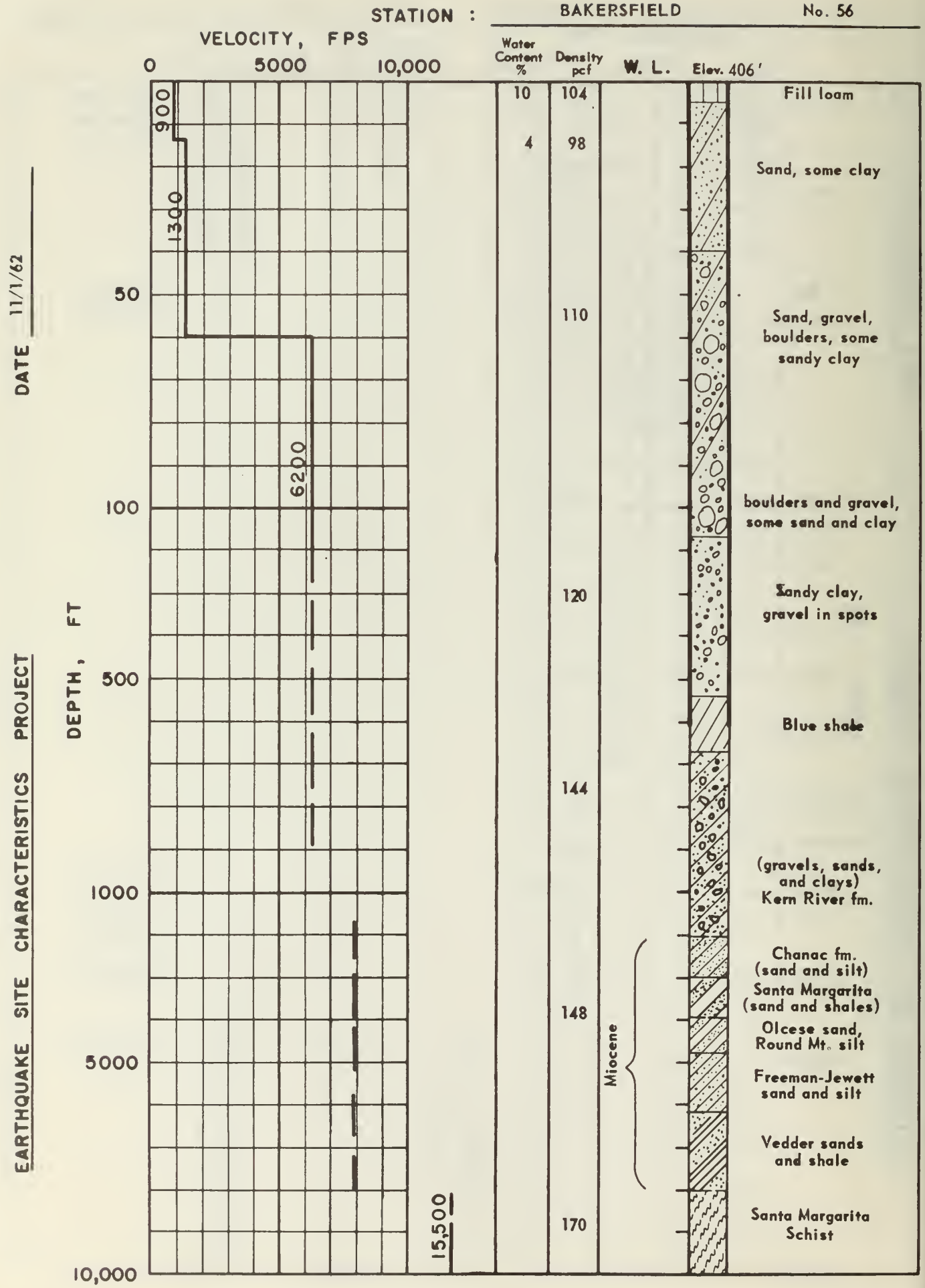


DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT


STATION : RIVERSIDE, LINCOLN SCHOOL No. 54
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 855'
800
2100
3400
16,200
2-10
5
20
1-2
100
105
130
130
135
140
140
168
1933
1941, 52
1956
Fine sandy loam
Fine sand
Sandy clay
Younger alluvium
Gravel, some clay
Clay, gravel some sand
Clay
Gravel, sand, silt, and clay
Older alluvium
Compacted gravel, sand, silt, and clay
Early Pleistocene
Pliocene indurated clay
Mica schist
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

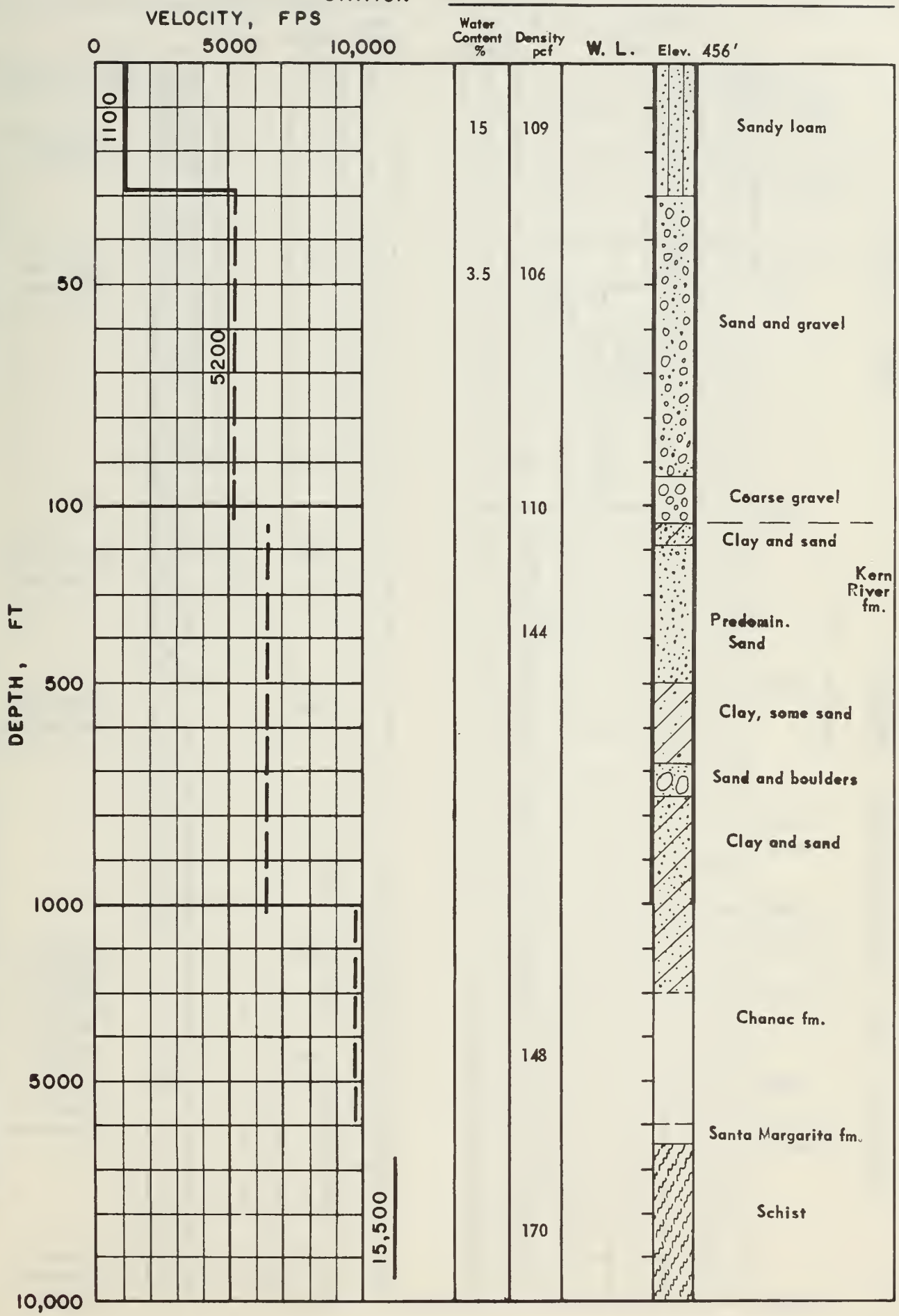

STATION : TAFT No. 55
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 900'
1190
1.5
30
65
140
144
148
170
15,500
Silty and sandy loam, sand, and (shale) gravel.
Tulare fm. (U. Pliocene)
San Joaquin fm. (Pliocene)
Reef Ridge fm. (Miocene)
Antelope fm. (Miocene)
Santa Margarita schist
DEPTH, FT
50
100
500
1000
5000
10,000
EARTHQUAKE SITE CHARACTERISTICS PROJECT
DATE 11/1/62

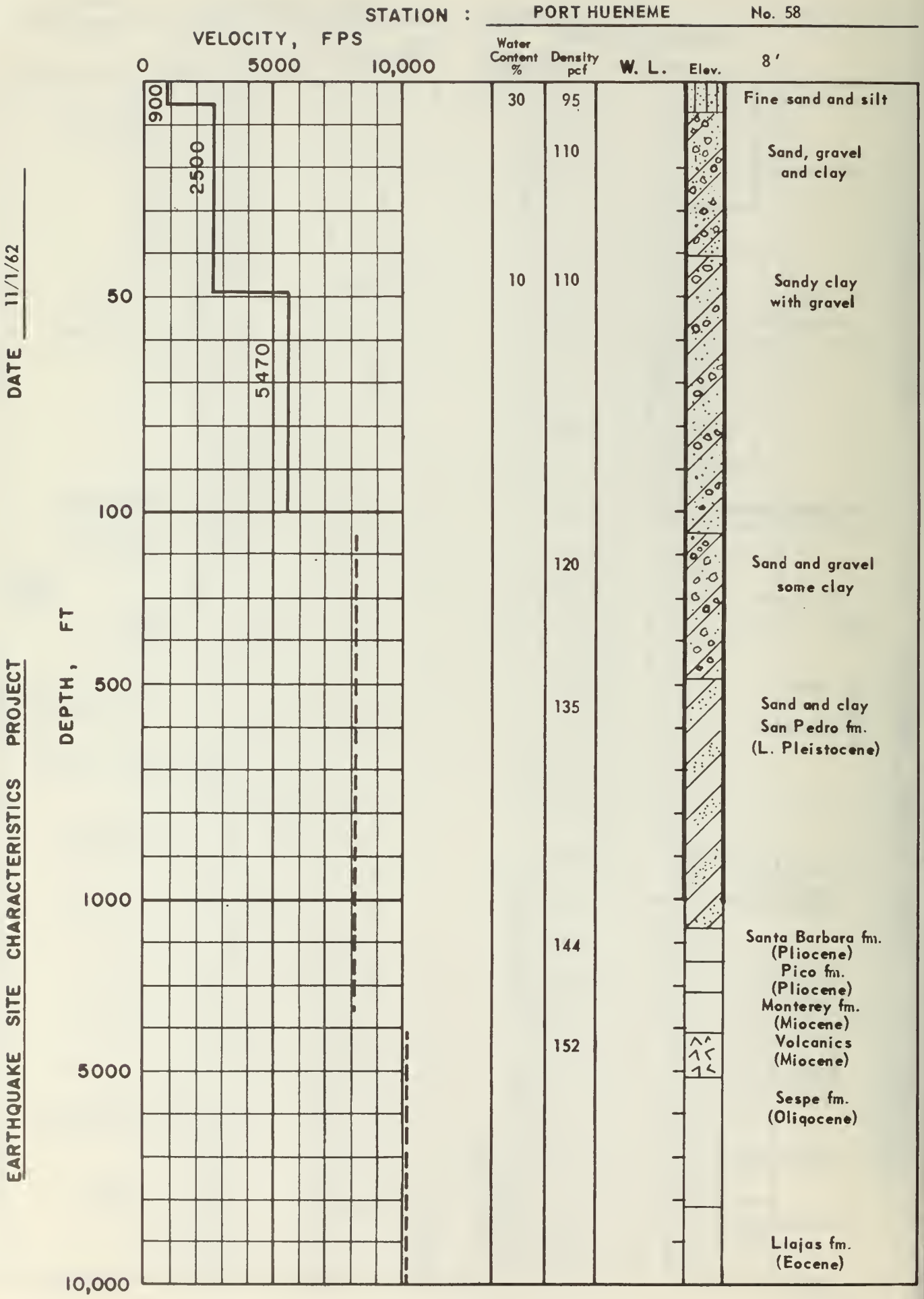

STATION : BAKERSFIELD No. 56
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 406'
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT
DEPTH, FT
50
100
500
1000
5000
10,000
900
1300
6200
15,500
10
4
104
98
110
120
144
148
170
Miocene
Fill loam
Sand, some clay
Sand, gravel, boulders, some sandy clay
boulders and gravel, some sand and clay
Sandy clay, gravel in spots
Blue shale
(gravels, sands, and clays) Kern River fm.
Chanac fm. (sand and silt)
Santa Margarita (sand and shales)
Olcese sand, Round Mt. silt
Freeman-Jewett sand and silt
Vedder sands and shale
Santa Margarita Schist

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : ARVIN HIGH SCHOOL No. 57

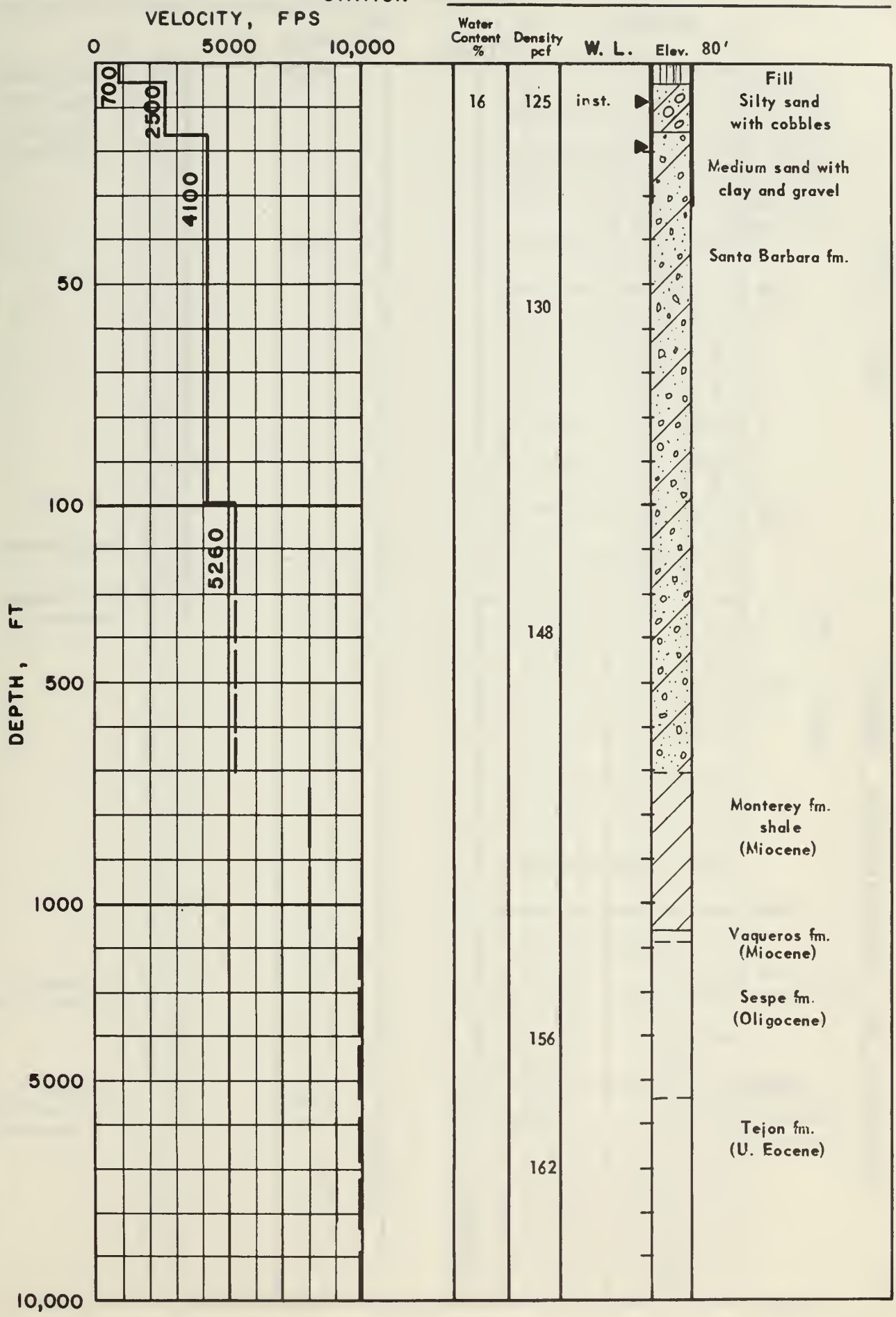


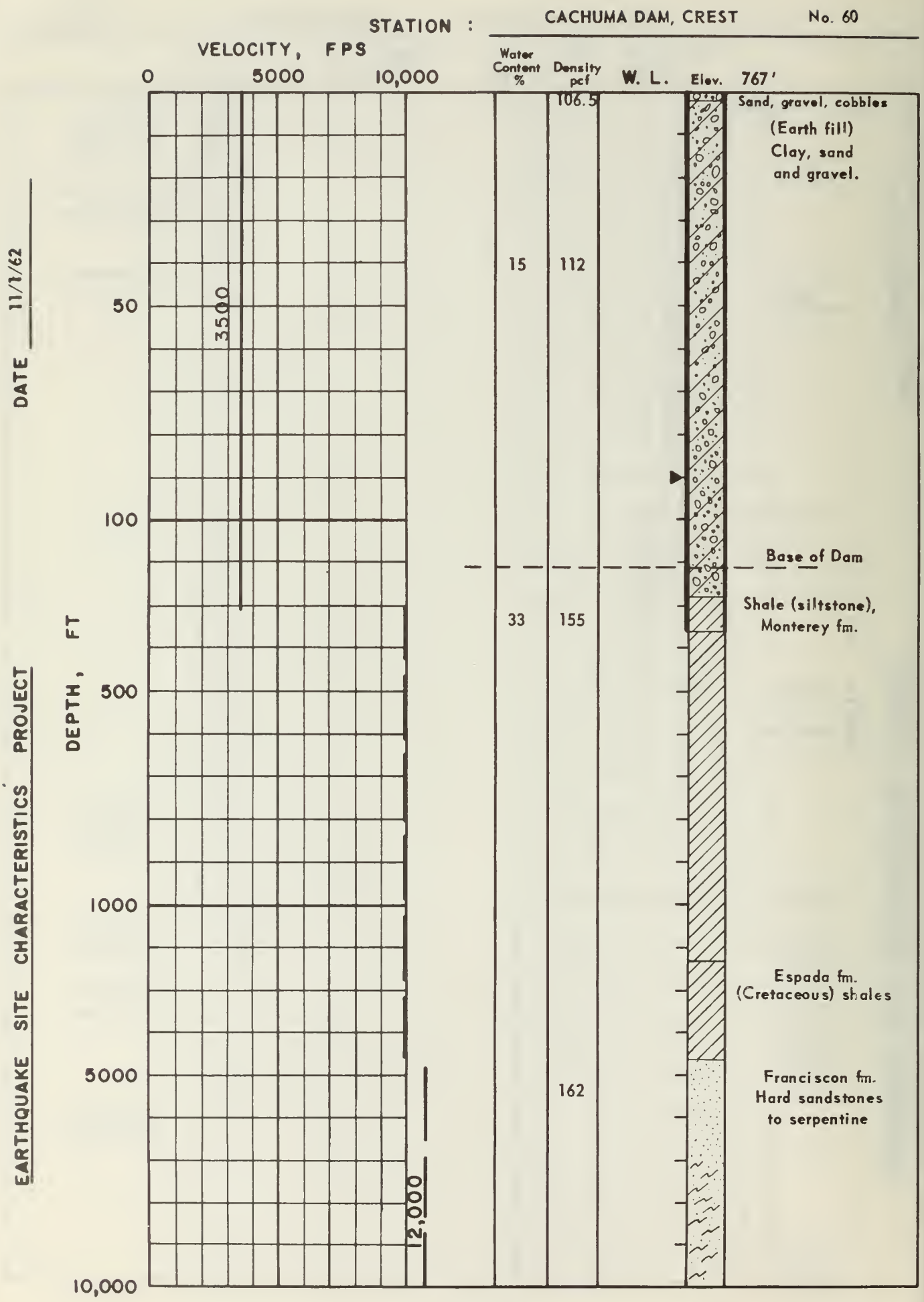

STATION : PORT HUENEME No. 58
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev.
8'
900
2500
5470
30
95
Fine sand and silt
110
Sand, gravel and clay
10
110
Sandy clay with gravel
120
Sand and gravel some clay
135
Sand and clay San Pedro fm. (L. Pleistocene)
144
Santa Barbara fm. (Pliocene)
Pico fm. (Pliocene)
Monterey fm. (Miocene)
152
Volcanics (Miocene)
Sespe fm. (Oligocene)
Llajas fm. (Eocene)
DEPTH, FT
50
100
500
1000
5000
10,000
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

EARTHQUAKE SITE CHARACTERISTICS PROJECT

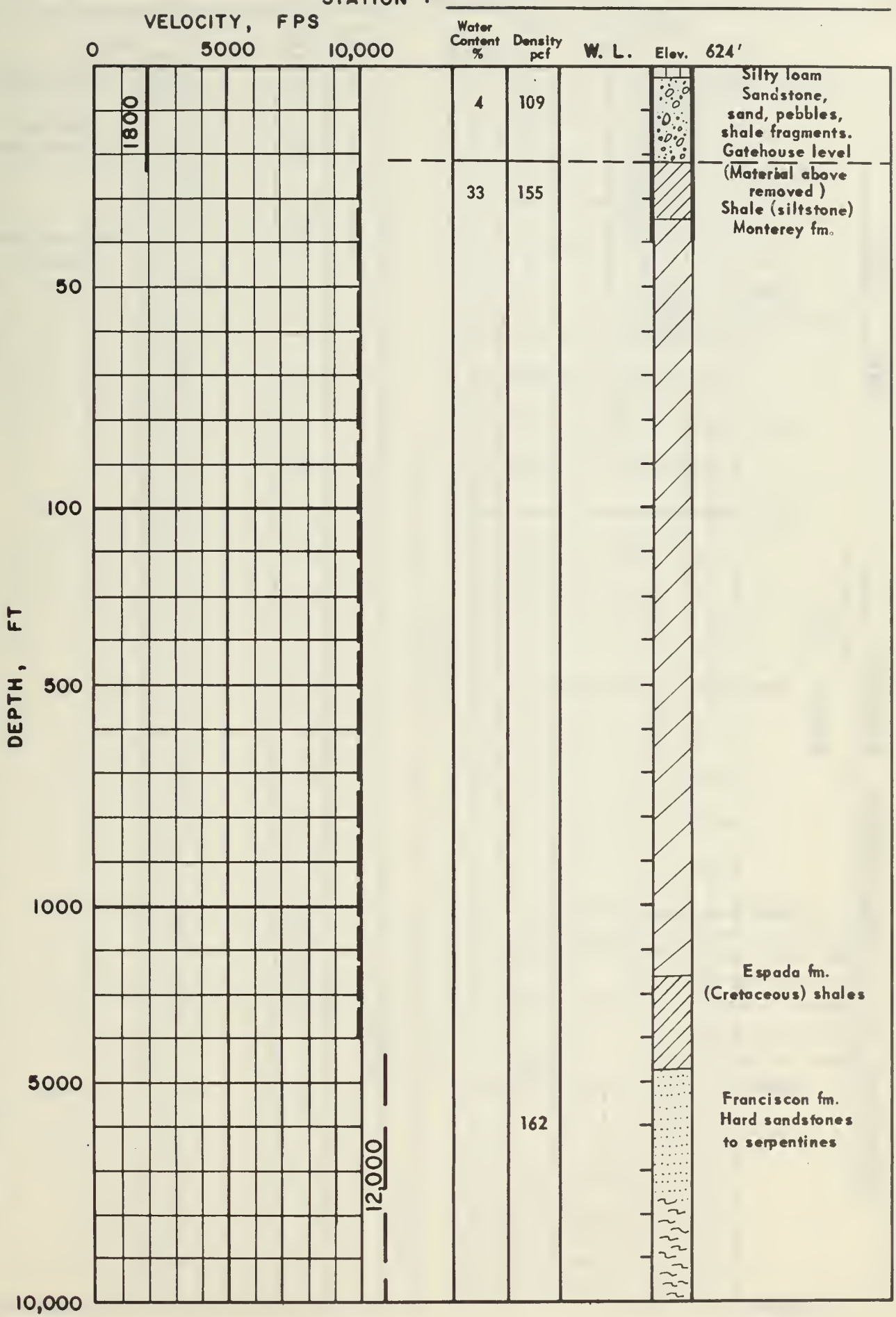
DATE 11/1/62

STATION : SANTA BARBARA, No. 59



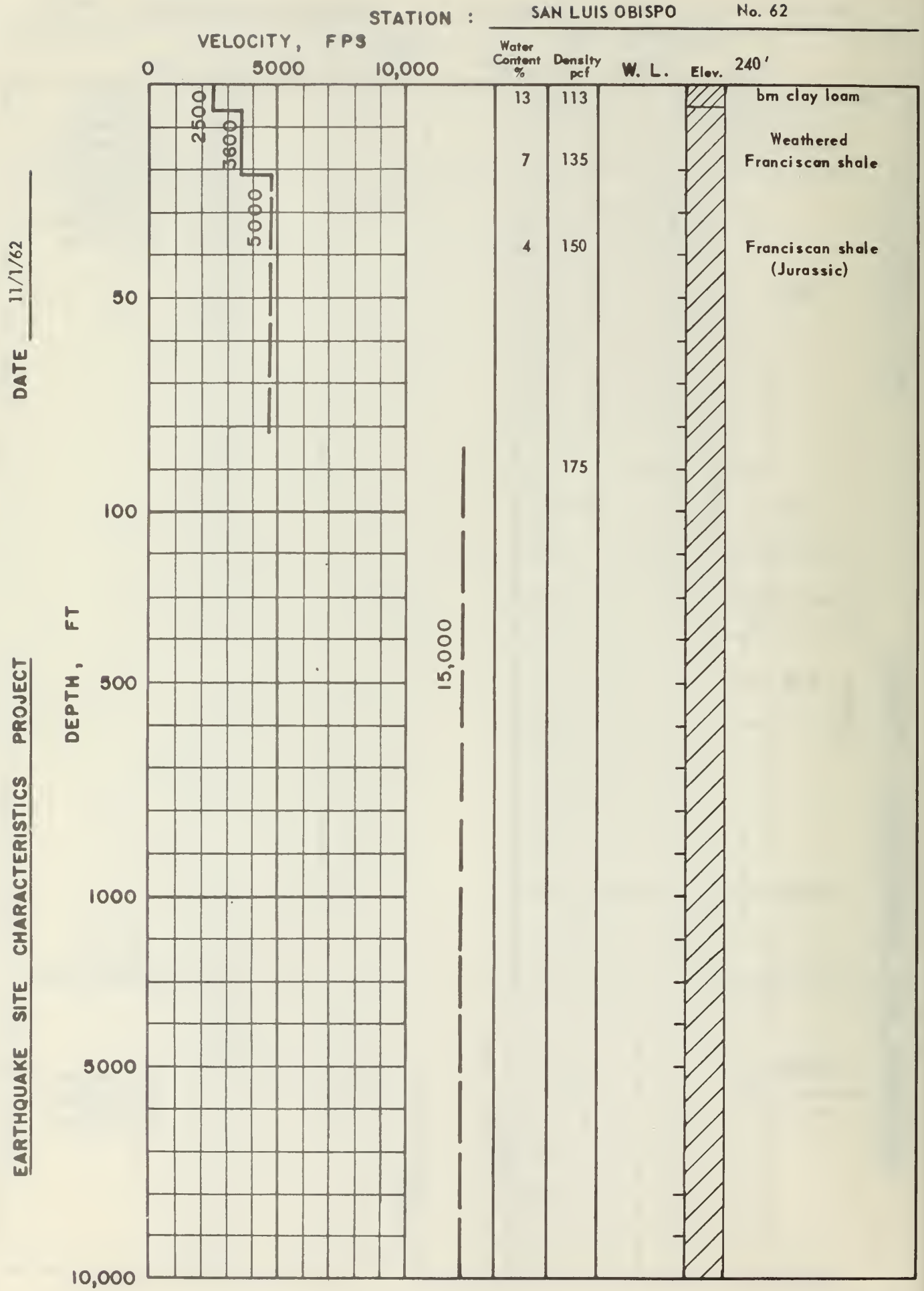

STATION : CACHUMA DAM, CREST No. 60
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 767'
106.5
Sand, gravel, cobbles
(Earth fill)
Clay, sand
and gravel.
15
112
3500
50
100
Base of Dam
Shale (siltstone),
Monterey fm.
33
155
500
1000
Espada fm.
(Cretaceous) shales
5000
162
Franciscon fm.
Hard sandstones
to serpentine
12,000
10,000
DEPTH, FT
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT

STATION : CACHUMA DAM, GATE HOUSE No. 61

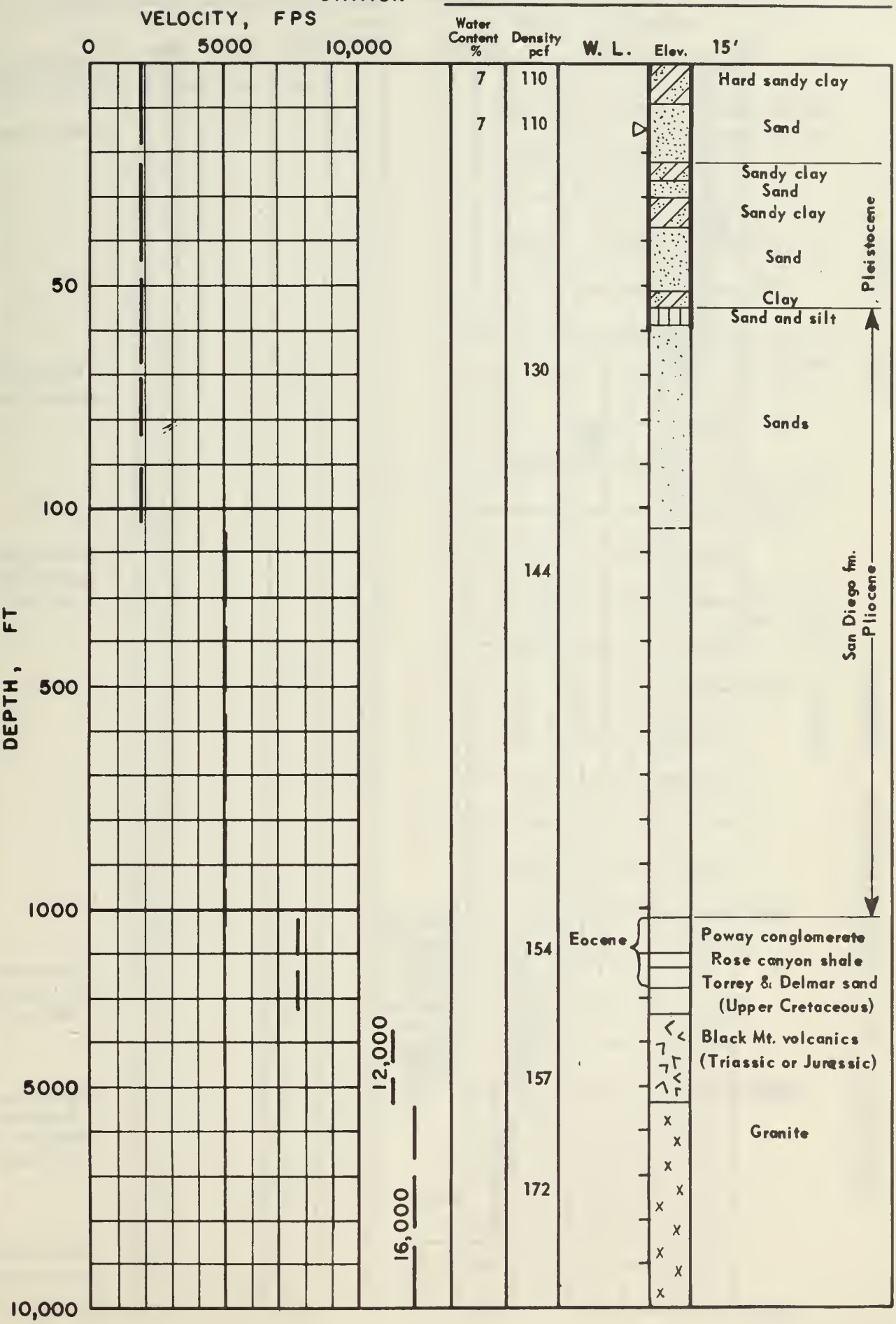


DATE 11/1/62

EARTHQUAKE SITE CHARACTERISTICS PROJECT

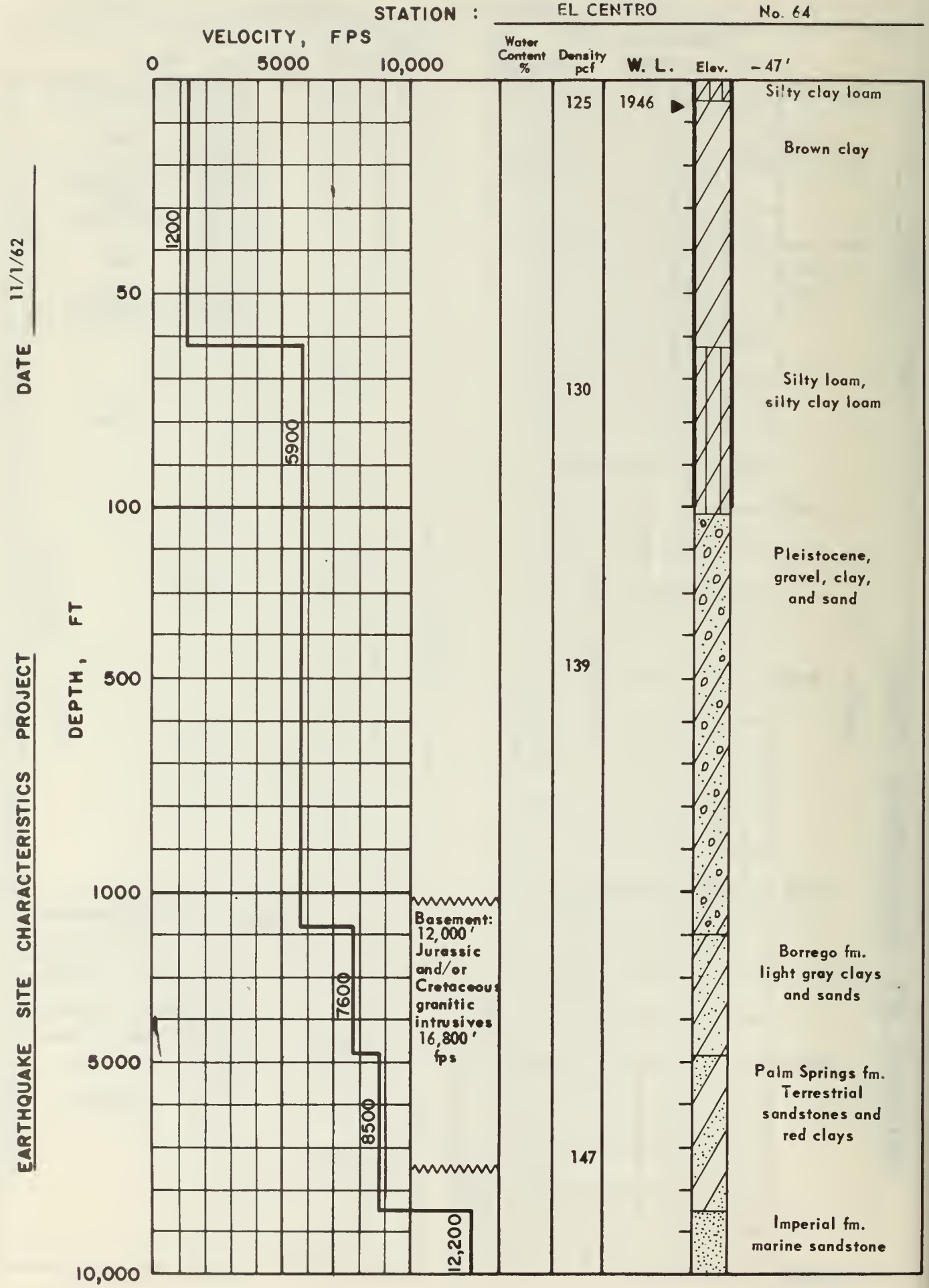

EARTHQUAKE SITE CHARACTERISTICS PROJECT
DATE 11/1/62
STATION : SAN LUIS OBISPO No. 62
VELOCITY, FPS
0
5000
10,000
2500
3600
5000
15,000
DEPTH, FT
50
100
500
1000
5000
10,000
Water Content %
Density pcf
W. L.
Elev. 240'
13
113
7
135
4
150
175
bm clay loam
Weathered Franciscan shale
Franciscan shale (Jurassic)

STATION : SAN DIEGO No. 63



DATE 11/1/62

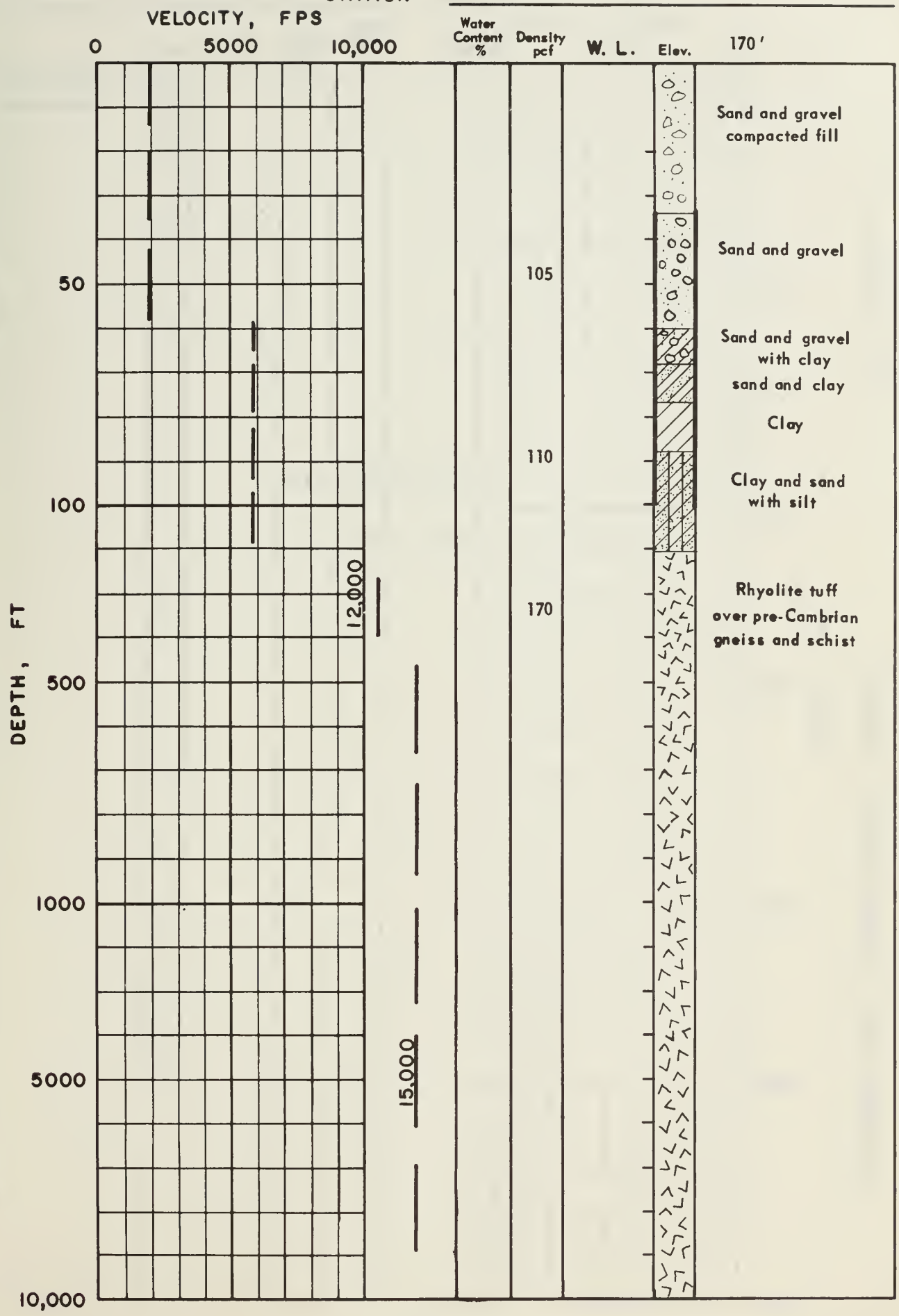
EARTHQUAKE SITE CHARACTERISTICS PROJECT


STATION : EL CENTRO No. 64
VELOCITY, FPS
0
5000
10,000
Water Content %
Density pcf
W. L.
Elev. – 47'
DATE 11/1/62
EARTHQUAKE SITE CHARACTERISTICS PROJECT
DEPTH, FT
50
100
500
1000
5000
10,000
1200
5900
7600
8500
12,200
125
130
139
147
1946
Basement: 12,000' Jurassic and/or Cretaceous granitic intrusives 16,800' fps
Silty clay loam
Brown clay
Silty loam, silty clay loam
Pleistocene, gravel, clay, and sand
Borrego fm. light gray clays and sands
Palm Springs fm. Terrestrial sandstones and red clays
Imperial fm. marine sandstone

EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

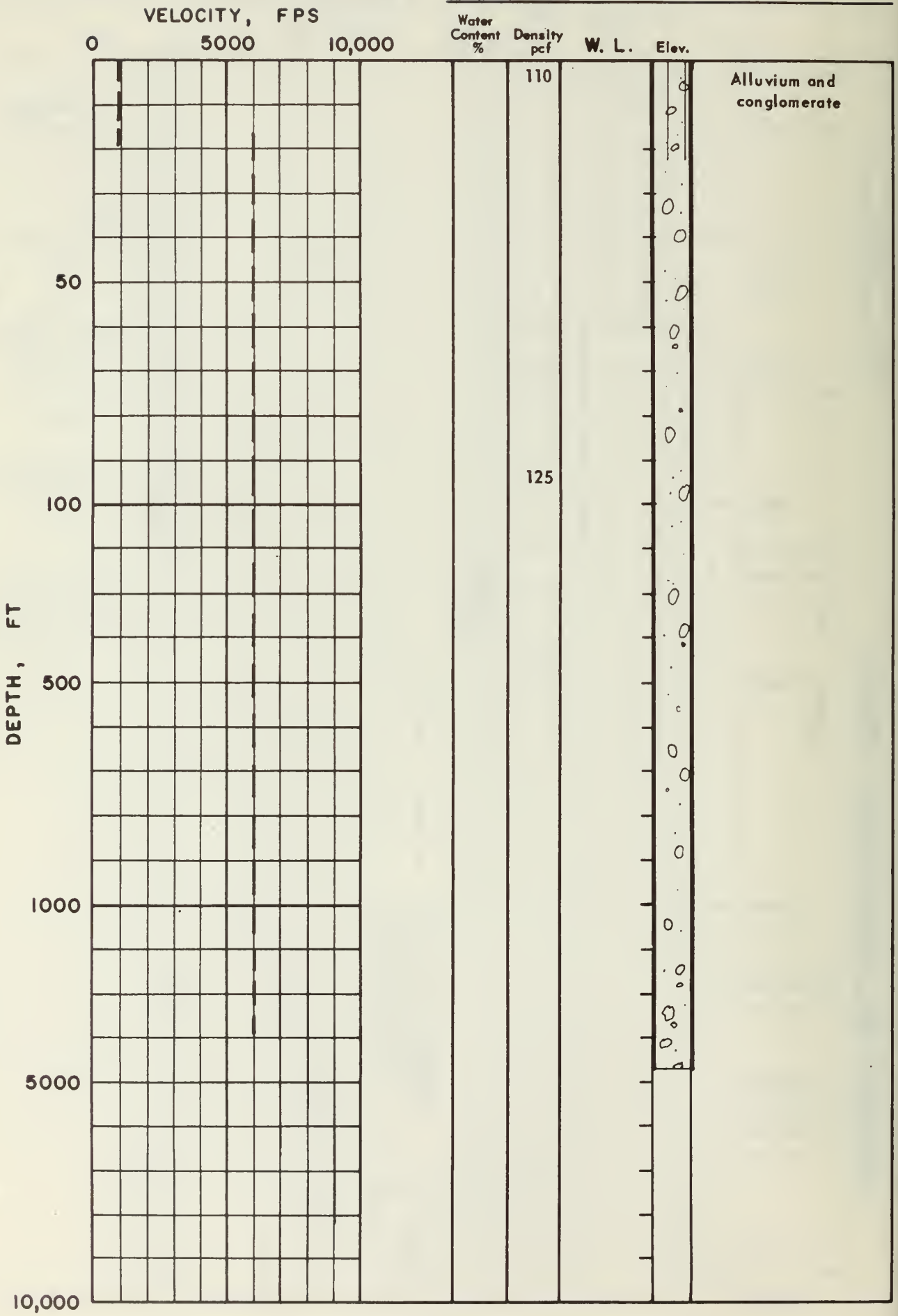
STATION : IMPERIAL DAM No. 65



EARTHQUAKE SITE CHARACTERISTICS PROJECT

DATE 11/1/62

STATION : SAN LUIS, ARIZONA No. 66



APPENDIX B

Site Data

SITE DATA

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
1	LOS ANGELES SUBWAY TERMINAL				
	30	1800	120	0.41	737
	370	3500	128	0.41	1434
	1600	8000	137	0.44	3519
	3000	8900	148	0.44	3915
	3000	9600	145	0.51	4895
		16000	166	0.61	9759
2	LOS ANGELES EDISON BLDG				
	30	1800	120	0.41	737
	370	3000	128	0.41	1229
	1600	8000	137	0.44	3519
	3000	8900	148	0.44	3915
	3000	9600	145	0.51	4895
		16000	166	0.61	9759
3	LOS ANGELES OCCIDENTAL LIFE BLDG				
	480	1700	130	0.45	764
	520	3600	137	0.41	1475
	1000	8000	137	0.44	3519
	4000	9000	148	0.44	3959
	2200	9600	145	0.51	4895
		16000	166	0.61	9759
4	LA EXPOSITION PARK				
	21	1100	110	0.45	494
	99	2200	137	0.41	901
	1680	6000	137	0.44	2639
	5700	7900	148	0.48	3791
		16000	166	0.61	9759
5	VERNON				
	40	396	110	1.00	396
	60	2480	115	1.00	2480
	1800	3790	137	1.00	3790
	3300	5240	137	1.00	5240
	3000	7500	148	1.00	7500
		10000	166	1.00	10000
6	HUNTINGTON PARK CITY HALL				
	50	1000	100	0.48	479
	50	2000	115	0.45	899
	500	5800	125	0.44	2551
	7400	8000	148	0.45	3599
		15500	170	0.61	9454

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
7	HOLLYWOOD STORAGE BLDG				
	15	1090	110	0.41	446
	185	2400	120	0.45	1079
	550	5000	135	0.48	2399
	1500	6500	137	0.48	3119
	5000	8500	148	0.48	4079
		16000	166	0.58	9279
8	LOS ANGELES HANCOCK PARK				
	10	1100	130	0.41	450
	30	2100	124	0.41	860
	260	4800	131	0.48	2303
	700	6500	137	0.48	3119
	7000	8300	148	0.51	4232
		16000	166	0.58	9279
9	L.A., WESTWOOD				
	10	1200	95	0.47	563
	20	1900	95	0.47	892
	40	6000	95	0.41	2459
	530	8000	130	0.45	3599
	4500	10000	137	0.48	4799
		16000	166	0.58	9279
10	WEST LA PUBLIC LIBRARY				
	11	1200	85	0.45	539
	23	1900	85	0.45	854
	316	5500	130	0.48	2639
	2650	6700	137	0.45	3014
	2000	7800	144	0.48	3743
	3000	10000	148	0.48	4799
		15000	166	0.58	8699
11	BRENTWOOD DUKE RES				
	9	950	100	0.44	417
	21	2350	100	0.44	1033
	50	3400	100	0.44	1495
		16000	166	0.58	9279
12	PACIFIC PALISADES				
	35	1200	105	0.45	539
	165	6000	95	0.41	2459
	1300	6000	146	0.46	2759
		16000	166	0.55	8799

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
13	L.A. WINDSOR HILLS ELEM. SCHOOL				
	20	750	105	0.44	329
	180	1900	125	0.43	816
	1800	7400	137	0.46	3403
	6500	8800	146	0.44	3871
		15000	170	0.61	9149
14	PLAYA ELEM. SCHOOL				
	30	1150	90	0.41	471
	220	2500	105	0.48	1199
	5750	5800	140	0.48	2783
		15500	170	0.61	9454
15	L.A. WESTCHESTER LEEDS RES				
	5	650	112	0.48	311
	175	2500	120	0.48	1199
	320	4500	115	0.48	2159
	7500	5800	144	0.46	2667
		15500	170	0.61	9454
16	L.A. HYPERION PLANT				
	55	1000	110	0.44	439
	55	5800	110	0.44	2551
	300	5800	130	0.48	2783
	2600	5800	135	0.48	2783
	4000	5800	156	0.48	2783
		15500	170	0.61	9454
17	HARBOR CITY				
	50	1450	100	0.48	695
	50	2000	125	0.27	539
	1900	6000	137	0.50	3000
	5000	6000	148	0.48	2879
		15500	170	0.61	9454
18	SAN PEDRO HIGH SCHOOL				
	40	1150	115	0.37	425
	110	1800	124	0.45	809
	1850	5300	137	0.48	2543
	2000	8200	148	0.48	3935
		15500	170	0.61	9454

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
19	LONG BEACH, EDISON PLANT				
	5	1000	95	0.48	479
	245	1600	130	0.37	591
	500	2000	137	0.41	819
	4250	5600	137	0.48	2687
	3500	7700	148	0.48	3695
		15500	170	0.61	9454
20	LONG BEACH, UTILITIES BLDG				
	10	950	107	0.44	417
	60	1600	130	0.44	703
	430	2500	130	0.48	1199
	1800	5500	137	0.48	2639
	6000	9000	145	0.48	4319
		15500	170	0.61	9454
21	COMPTON SCHOOL				
	25	1000	90	0.41	409
	225	1890	100	0.41	774
	200	4500	95	0.41	1844
	350	5700	120	0.44	2507
	11200	8700	148	0.48	4175
		15000	170	0.61	9149
22	SOUTHGATE HIGH SCHOOL				
	65	1750	120	0.44	769
	135	5700	120	0.44	2507
	2800	7500	135	0.45	3374
	2200	9000	137	0.44	3959
	7000	12000	148	0.48	5759
		16000	166	0.61	9759
23	HIGHLAND PARK				
	20	2000	125	0.51	1019
	180	7800	125	0.51	3977
	3800	8800	145	0.48	4223
		18000	172	0.61	10979
24	ELYSIAN HTS SCHOOL				
	20	2000	100	0.44	879
	50	6000	100	0.41	2459
	2930	8000	137	0.51	4079
		16000	166	0.58	9279

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
25	GLENDALE HOOVER HIGH SCHOOL				
	15	1050	121	0.41	430
	385	2000	126	0.48	959
	600	6100	140	0.53	3232
	7500	8000	148	0.48	3839
		16000	166	0.61	9759
26	VAN NUYS HIGH SCHOOL				
	35	1130	110	0.44	497
	165	2000	115	0.50	1000
	350	5470	127	0.45	2461
	5450	8000	146	0.53	4239
		16000	172	0.61	9759
27	MT WILSON OBS				
	5	1200	110	0.45	539
	70	2200	135	0.50	1100
		18000	172	0.61	10979
28	ALTADENA PRESS RES				
	10	1500	105	0.48	719
	55	2500	135	0.50	1250
		18000	177	0.61	10979
29	PASADENA GILMAN RES				
	9	850	105	0.44	373
	26	1100	105	0.48	527
	65	2500	135	0.50	1250
		18000	172	0.61	10979
30	WASHINGTON JHS				
	45	2000	135	0.50	1000
	155	13700	172	0.61	8356
		18000	172	0.61	10979
31	JOHN MUIR SCHOOL				
	25	2500	125	0.50	1250
	275	4000	130	0.50	2000
	200	7600	130	0.50	3800
		18000	172	0.61	10979

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
32	PASADENA MOTTA RES				
	20	1100	110	0.48	527
	78	4400	129	0.48	2111
	102	5200	172	0.48	2495
		18000	172	0.61	10979
33	PASADENA HALE ELEM SCHOOL				
	13	900	125	0.44	395
	17	2250	125	0.50	1125
	970	4200	131	0.48	2015
		18000	172	0.61	10979
34	PASADENA NORDQUIST RES				
	11	800	120	0.47	375
	289	4000	130	0.50	2000
	1000	7500	131	0.48	3599
		18000	172	0.61	10979
35	PASADENA STAR NEWS BLDG				
	9	1100	112	0.47	516
	91	2400	129	0.50	1200
	150	5200	135	0.48	2495
	550	7500	135	0.48	3599
		18000	172	0.61	10979
36	CALTECH SEISMO LAB				
	60	5300	172	0.61	3232
		18000	172	0.61	10979
37	PASADENA SAN RAFAEL SCHOOL				
	5	1000	110	0.47	469
	20	1900	120	0.50	950
	975	4500	130	0.48	2159
		18000	172	0.61	10979
38	PASADENA GARFIELD ELEM SCHOOL				
	15	1100	122	0.44	483
	20	2550	132	0.44	1121
	265	4500	130	0.44	1979
	200	5400	172	0.42	2267
		18000	172	0.61	10979

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
39	PASADENA, CALIFORNIA INSTITUTE OF TECHNOLOGY				
	10	1000	110	0.44	439
	140	2200	120	0.53	1165
	200	5300	125	0.50	2650
	1000	7500	131	0.47	3524
		18000	172	0.61	10979
40	SAN MARINO CITY HALL				
	59	1660	127	0.50	830
	301	4200	131	0.45	1889
	550	5100	131	0.45	2294
	4100	8000	144	0.48	3839
		18000	172	0.61	10979
41	ALHAMBRA TAYLOR RES				
	28	900	105	0.45	404
	72	5500	110	0.45	2474
	1900	6500	140	0.44	2859
	4000	7800	140	0.48	3743
		18000	172	0.61	10979
42	EAST LOS ANGELES JR COLLEGE				
	30	1000	119	0.41	409
	70	1100	110	0.48	527
	100	1200	122	0.50	600
	800	5100	144	0.45	2294
	7000	8800	156	0.48	4223
		18000	172	0.55	9899
43	SANTA ANA				
	25	1000	106	0.41	409
	70	2000	130	0.45	899
	275	4200	134	0.44	1847
	4130	7100	137	0.45	3194
		16000	166	0.61	9759
44	BISHOP				
	10	1000	90	0.41	409
	1290	5900	125	0.45	2654
	2600	6900	162	0.58	4001
		15700	170	0.61	9576

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
45	HAWTHORNE NEVADA				
	5	1000	100	0.48	479
	25	2500	100	0.50	1250
	320	6500	103	0.50	3250
	4000	6500	140	0.48	3119
		16000	170	0.61	9759
46	HOOVER DAM GALLERY				
	400	7000	162	0.23	1609
	200	12000	165	0.23	2759
		16000	181	0.27	4319
47	HOOVER DAM INTAKE TOWER				
	300	6800	162	0.23	1563
	700	12000	165	0.23	2759
		16000	181	0.27	4319
48	HOOVER DAM OILHOUSE				
	500	6900	162	0.23	1586
	500	12000	165	0.23	2759
		16000	181	0.27	4319
49	TABLE MT				
	20	6000	160	0.50	3000
		16000	172	0.61	9759
50	ARROWHEAD SPRINGS				
	40	7800	135	0.61	4757
		16000	172	0.61	9759
51	SAN BERNARDINO				
	20	1300	90	0.45	584
	180	5200	110	0.48	2495
	3800	5800	130	0.48	2783
		16200	168	0.61	9881
52	COLTON EDISON				
	19	1375	80	0.50	687
	261	5200	100	0.48	2495
	3720	6100	130	0.48	2927
		16200	168	0.61	9881
53	RIVERSIDE SEISMO LAB				
	80	7800	166	0.58	4523
		15000	168	0.58	8699

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
54	RIVERSIDE LINCOLN SCHOOL				
	13	800	100	0.45	359
	28	2100	105	0.47	986
	49	3400	130	0.45	1529
	910	6000	140	0.47	2819
	4000	6800	145	0.58	3943
		16200	168	0.58	9395
55	TAFT				
	40	1190	140	0.45	535
	160	5000	144	0.48	2399
	500	6500	144	0.48	3119
	3300	8000	148	0.48	3839
		15500	170	0.61	9454
56	BAKERSFIELD				
	15	900	104	0.42	377
	45	1300	98	0.47	610
	140	6200	115	0.50	3100
	900	6200	131	0.45	2789
	7000	8000	148	0.48	3839
		15500	170	0.61	9454
57	ARVIN				
	29	1100	109	0.44	483
	121	5200	109	0.50	2600
	860	6400	144	0.48	3071
	5000	9800	148	0.53	5193
		15500	170	0.58	8989
58	PORT HUENEME				
	5	900	95	0.45	404
	44	2500	110	0.47	1174
	51	5470	120	0.45	2461
	3900	8200	140	0.45	3689
		10200	152	0.58	5915
59	SANTA BARBARA				
	5	700	125	0.41	286
	10	2500	125	0.48	1199
	85	4100	130	0.47	1926
	600	5260	148	0.47	2472
	1800	8000	150	0.48	3839
		10000	162	0.58	5799

Sta. No.	Thickness feet	V_p fps	Density pcf	V_s/V_p	V_s fps
60	CACHUMA DAM CREST				
	300	3500	112	0.45	1574
	4700	10000	155	0.48	4799
		12000	162	0.53	6359
61	CACHUMA DAM GATE HOUSE				
	25	1800	109	0.51	917
	3975	10000	155	0.48	4799
		12000	162	0.53	6359
62	SAN LUIS OBISPO				
	5	2500	113	0.41	1024
	16	3600	135	0.48	1727
	59	5000	150	0.52	2599
		15000	175	0.53	7949
63	SAN DIEGO				
	150	1900	125	0.48	911
	850	5000	144	0.48	2399
	2000	7700	154	0.48	3695
	2000	12000	157	0.53	6359
		16000	172	0.61	9759
64	EL CENTRO				
	100	522	128	1.00	522
	1000	2810	139	1.00	2810
	3000	3620	139	1.00	3620
	3500	4050	147	1.00	4050
	3500	7200	147	1.00	7200
		10000	172	1.00	10000
65	IMPERIAL DAM				
	60	2000	105	0.50	1000
	140	5800	110	0.45	2609
	200	12000	170	0.61	7319
		15000	170	0.61	9149
66	SAN LUIS ARIZONA				
	20	1000	110	0.48	479
		6000	125	0.48	2879

APPENDIX C

Amplification Spectra

ONE-LAYER SITES

36	Seismological Laboratory, Pasadena
49	Table Mountain
50	Arrowhead Springs
53	Seismograph Station, Riverside
66	San Luis, Arizona

2XX 6-13-72